DISCOVERY

Monthly Notebook

Fifty Years of Nobel Prizes
Potash in Yorkshire
Transmitting Electricity over Long Distances

The Thunder-storm : A Natural Dynamo

Prof. P. A. SHEPPARD, B.Sc., F.Inst.P.

Maleic Hydrazide

Prof. D. G. WHITE

Biological Warfare

CHAPMAN PINCHER, B.Sc.

Robert Boyle

C. L. BOLTZ

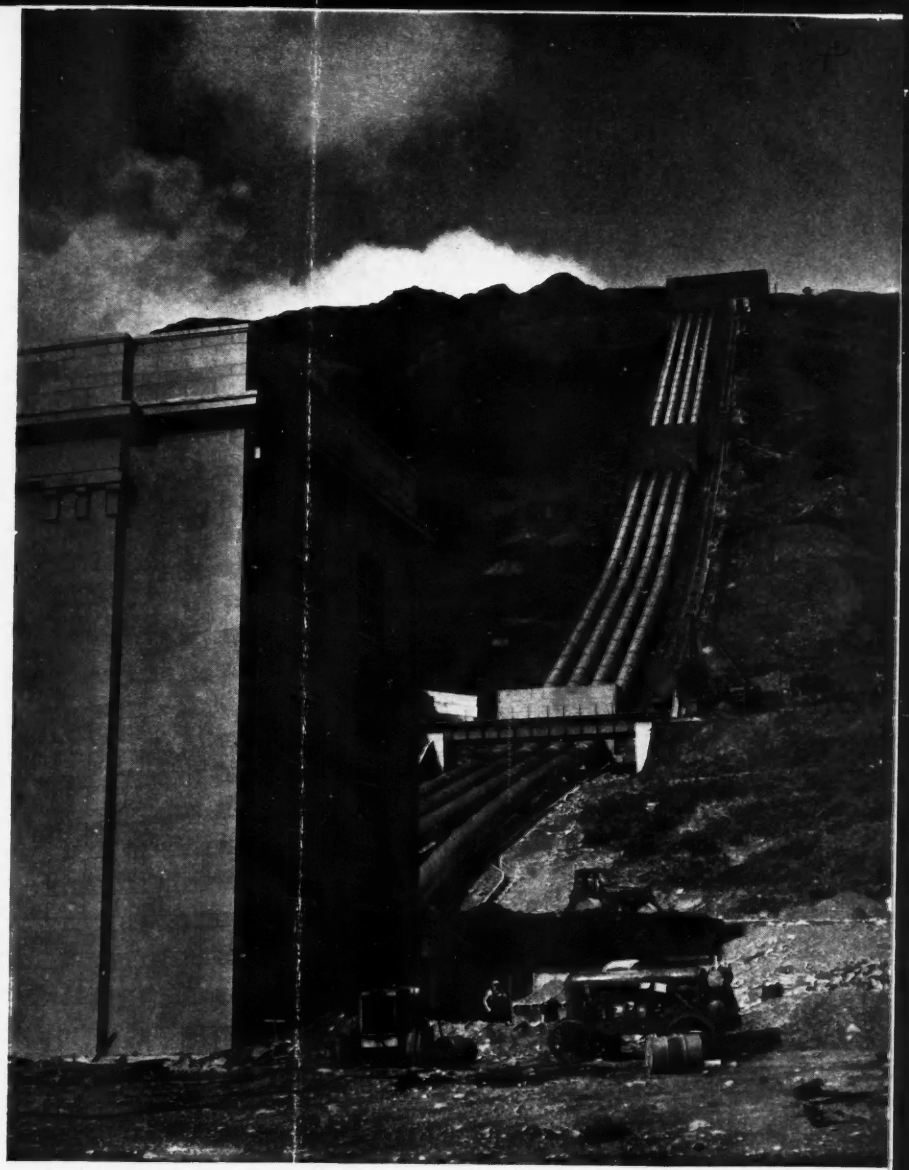
The Mechanics of Snakes

A. LEUTSCHER, B.Sc., F.Z.S.

Power from the Highlands

Chroma-tography in Industry

TREVOR I. WILLIAMS, B.Sc., D.Phil.

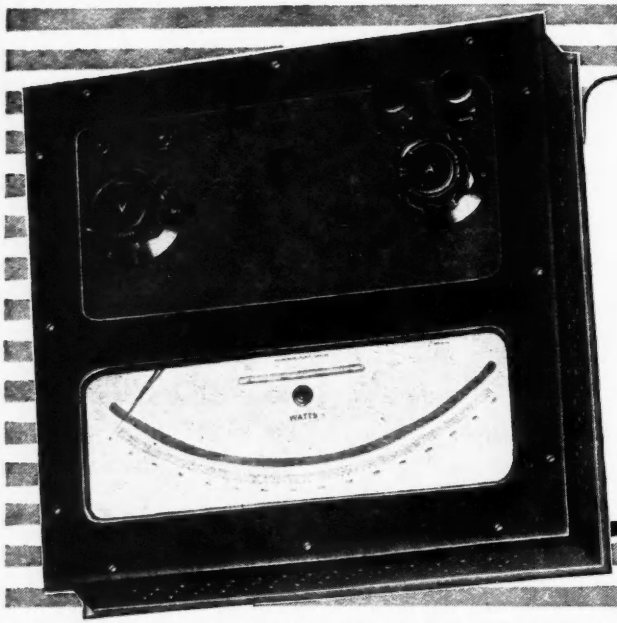


UNIVERSITY OF MICHIGAN
DEC 27 1950
PERIODICAL READING ROOM

DECEMBER

1950

1/6



WESTON

12-INCH SCALE LABORATORY STANDARDS

For measurements of extreme accuracy in laboratory, research and industrial use

ACCURACY 0·1 per cent

SANGAMO WESTON LIMITED

ENFIELD, MIDDLESEX *Telephone: Enfield 3434 (6 lines) and 1242 (4 lines)* *Telegrams: Sanwest, Enfield*

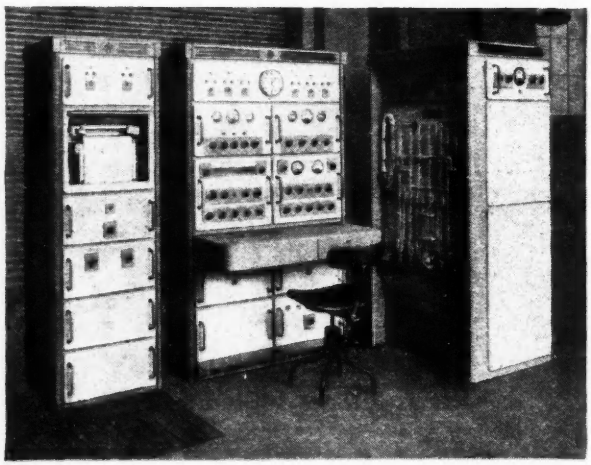
BRANCHES: GLASGOW, MANCHESTER, NEWCASTLE-ON-TYNE, LEEDS, WOLVERHAMPTON, BRISTOL, SOUTHAMPTON, BRIGHTON

MASS SPECTROMETER *Type M.S. 2*

THIS is a general purpose instrument covering the mass range 1 to 250. Any of the more common mass spectrometry problems—isotope assays, studies of ionisation and dissociation, analyses of hydrocarbon mixtures—can be carried out.

The instrument has been arranged in three units. The first contains the all-metal spectrometer tube, magnet, vacuum system and gas handling plant. The second houses all the electronic stabilisers, power supplies and the controls necessary for manual operation. The third—which may be ordered optionally—includes an automatic sweep control and a pen-type abundance recorder with automatic range-changing.

This instrument is described in Descriptive Leaflet 905/10-1



METROPOLITAN-VICKERS ELECTRICAL CO. LTD., TRAFFORD PARK, MANCHESTER 17

Member of the A.E.I. group of companies

NA/002

METROVICK *Equipment for Science and Industry*

As a record of the progress in science and industry achieved very largely under British leadership in the century between the Great Exhibition of 1851 and the Festival of Britain of 1951 two books are being issued early next year, written by specialist authors and covering the most important developments in theory and practice.

A Century of Technology

Edited by

PERCY DUNSHEATH, C.B.E., D.SC., M.A.

Past President of the Institution of Electrical Engineers

A Century of Science

Edited by

HERBERT DINGLE, D.SC.

Professor of History and Philosophy of Science in the University of London

Both books will be illustrated and priced at about 12s. 6d. each

HUTCHINSON'S

SCIENTIFIC & TECHNICAL PUBLICATIONS

Hutchinson House, London, W.1.

Telephone: **EUSton 4282**

BOOKS

LARGE STOCK OF NEW & STANDARD BOOKS ON CHEMISTRY—PURE AND APPLIED, PHYSICS, MATHEMATICS, BIOLOGY, PSYCHOLOGY, ENGINEERING, AGRICULTURE. STUDENTS' TEXT-BOOKS FOR ALL SCIENTIFIC EXAMINATIONS SUPPLIED.

Please state interests when writing

SCIENTIFIC LENDING LIBRARY

Annual subscription from ONE GUINEA

The Library covers a wide range of subjects and is invaluable to schoolmasters and students.

Prospectus post free on request

THE LIBRARY CATALOGUE revised to December, 1949, containing a classified index of authors and subjects, is in preparation

SECOND-HAND BOOKS

140, GOWER STREET, LONDON, W.C.1

Large stocks of recent editions of scientific and technical works available

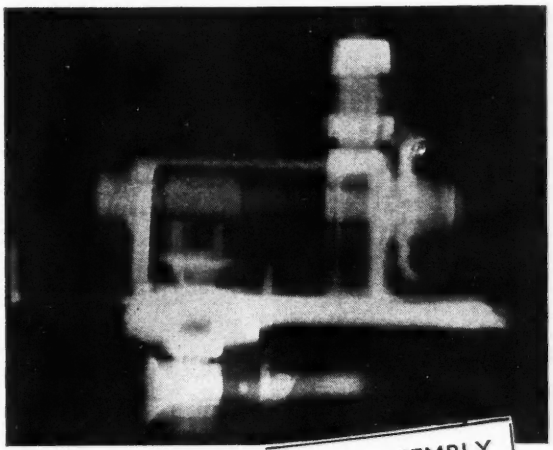
LONDON

H. K. LEWIS & Co. Ltd.

136, GOWER STREET, W.C.1

Established 1844

CLOSER INSPECTION —of heavy subjects



The good points—and the bad—about many industrial subjects lie well below the surface and the finest X-ray materials are essential for really close inspection. For all such subjects Ilford Industrial Type A film satisfies the two equally important demands for speed and high definition.

Radiographs of heavy steel subjects can be made satisfactorily with Ilford Industrial X-ray film Type A and either Ilford Lead Screens or Ilford High Definition Salt Screens. Other techniques are given in the Ilford book "Ilford X-ray Films and Screens for Industrial Radiography."

ILFORD

X-ray films and screens

for

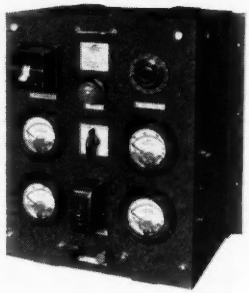
Industrial Radiography

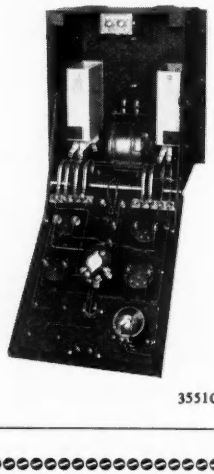
ILFORD LIMITED · ILFORD · LONDON

Legg

LOW-VOLTAGE POWER UNIT

This low-voltage power unit has been designed to meet the needs of science teaching in secondary schools and provides an efficient source of low voltage A.C./D.C. power for experimental purposes in science laboratories. The front panel is hinged to expose the wiring and component parts for teaching and the interlocking isolation switch renders the unit 'dead' and quite safe to handle.





The unit has been produced to the requirements of the London County Council Education Committee and is already in use in a large number of schools throughout the country.

Legg (INDUSTRIES) LTD · WILLIAMSON ST · WOLVERHAMPTON

3551C

A selection of

BUTTERWORTHS Scientific Books

Wild Animals in Captivity

Just Published. By H. HEDIGER, Director, Zoological Gardens, Basle. Translated by *G. SIRCOM, B.A.*

"This represents the first attempt by a qualified zoologist to approach the subject from a scientific viewpoint . . . all those interested in either the care or behaviour of animals will find this book invaluable."—*Discovery.*

Price 35s., by post 10d. extra. Pp. 200 + Index. 30 illustrations.

Introductory Statistics

Just Published. By M. H. QUENOUILLE, M.A., Marischal College, Aberdeen.

In this work emphasis is laid upon new methods of interpretation and their consequences, rather than on long-standing methods of collection and presentation of data. It will appeal to scientists in all branches who require an insight into precise evaluation of results.

Price 30s., by post 1s. extra. Pp. xii + 244 + Index. 52 diagrams.

BUTTERWORTHS SCIENTIFIC PUBLICATIONS
BELL YARD, TEMPLE BAR, LONDON, W.C.2

Man is a Microcosm

Dr. J. A. V. BUTLER

"It has a twofold purpose: to outline modern knowledge concerning the basic phenomena of life; and by showing the extraordinary complexity and marvellous adaptations encountered in this realm, to correct the impression of life as a trivial accident and of man as not very different from a machine. The subjects discussed include proteins and amino-acids, the 'building stones' of life; the functions and inter-relations of enzymes, vitamins, genes and viruses; and finally the working of muscles, nerves and brain in relation to the processes of consciousness. Dr. Butler's book is clearly and simply written and illustrated with excellent photographs and diagrams."

CHARLES DAVY (*The Observer*). 10*s.* 6*d.*

Macmillan & Co. Ltd.

DISCOVERY

THE MAGAZINE OF SCIENTIFIC PROGRESS

December, 1950 Vol. XI. No. 12

Editor WILLIAM E. DICK, B.Sc., F.L.S.
Editorial Office: 244 High Holborn, W.C.1. Tel. Chancery 6518
Advertisement Office: Temple Chambers, Temple Avenue, London, E.C.4. Tel. City 6537 (Three Lines)
All Subscriptions, Distribution and Business Communications to Jarrold & Sons Ltd., Norwich. Tel. Norwich 25261

The Progress of Science

Fifty Years of Nobel Prizes

IT seems ironic that a fortune made from dynamite should provide the source of the most coveted prizes that are awarded in the field of intellectual endeavour. Yet that is the origin of the story of the Nobel prizes. Alfred Nobel, a Swede by birth but an international in outlook, spent many years of his life in Russia and in France and travelled extensively. An inventor without any scientific training, he discovered dynamite accidentally, and his discovery made him one of the richest munition magnates of the nineteenth century. But he seems genuinely to have hated war, and for a long time clung to the belief that the very destructiveness of sophisticated weapons of warfare such as high explosives was likely to put an end to war. Towards the end of his life, however, he seems to have lost much of his faith in the permanent establishment of universal peace. At any rate, in his will establishing the Nobel Prizes, the prize for the promotion of peace appears as the last; the first mentioned are those dearest to his heart—physics, chemistry, and physiology and medicine; then comes the prize for literature, and lastly that for peace.

The awards are still governed by the terms of Nobel's will. The prizes for physics and for chemistry are awarded by the Royal Academy of Sciences of Stockholm, the prize for physiology and medicine by the Royal Karolinska Medico-Surgical Institute of Stockholm, the prize for literature by the Stockholm Academy. Candidates may not propose themselves, and nominations can only be suggested by competent persons. In the case of the prizes for physics and chemistry these must be members either of the Royal Academy of Sciences or of the Nobel Committee for physics and chemistry, which is composed of former Nobel prizewinners in these subjects, professors in these subjects at the Universities of Uppsala, Lund, Oslo, Copenhagen, Helsinki, at the Karolinska Institute, at the Stockholm Polytechnic and at the Stockholm College, and finally scientists in other countries invited to do so by the Swedish Academy of Sciences. In the case of the prize for physiology and medicine the competent persons are the Senators of the Karolinska Institute, the medical members of the Swedish Academy of Sciences, former prizewinners in this class, professors of medical faculties of the Universities of Uppsala, Lund, Oslo, Copenhagen and Helsinki, and prominent teachers at other colleges authorised by the Senate of the Karolinska Institute. The prizes are distributed with great ceremony each year on December 10, the anniversary of Nobel's death, the recipients being awarded, besides the monetary prize, a diploma and a gold medal. This year there will be special celebrations in Stockholm to mark the jubilees. The assembled company will surely complete the greatest 'Brains Trust' in history, for all the living Nobel laureates have been invited to attend.

Ever since their inception in 1901, the Nobel prizes have been considered the highest distinction a scientist or writer or worker for peace can gain. This is partly due to the high monetary value of the prize. Five years after Nobel's death, when the Foundation was finally established in 1900, its funds amounted to 31 million kronor; and today they stand much higher. Each prize has ranged in value between 115,000 and 172,000 kroner, according to the year, making an average of £10,000; the value of the prizes epitomises Nobel's belief that "too little help was no help at all." But the fame of the Nobel prizes is really due to the fact that, from the beginning, they have been awarded with complete disregard for national or political considerations, and that, on the whole, the recipients have been men of outstanding merit in their field. This is particularly true of the prizes for science, though on more than one occasion the choice has been weighted by a rather too cautious conservatism. Planck had to wait 18 years before his quantum theory was rewarded, and Einstein got his prize not for his Theory of Relativity, but for the relatively minor discovery of the law of the photo-electric effect which he made years later.

But the table of the Nobel laureates in science tells, better than anything else could do, the magnificent story of the progress of science in the last fifty years. It also shows to what an overwhelming extent this progress has been the labour of the West. Between them Western Europe, including Germany and Austria, and the United States, account for well over 90% of the awards. Over the whole period of fifty years Germany easily tops the list, followed by Britain, the U.S.A. and France in that order.

But the table also reveals the striking changes that have occurred during this period in the relative contribution of the principal nations. In particular, it shows the very marked decline of France, which in the last twenty years has

gained only one prize. It shows, above all, the truly amazing rise of the United States, which in the same twenty years has won more awards than any other nation, and has now taken the place which Germany held for so long. No less significant, in a different way, is Britain's record—the story of a high and remarkably steady standard of achievement. Britain was second when Germany held first place; she is still second now that the U.S.A heads the list. German science still suffers from the devastation which twelve years of Nazi regime wrought upon it, but the record of Nobel prizes since 1945 indicates the Germans are capable of staging a spectacular comeback. This year's award is certainly a sign that German science is still alive and kicking.

The last few years have seen the appearance of newcomers in the Nobel list—a Japanese, an Argentinian, a Portuguese, a Finn. This may be a sign that other countries whose contribution has hitherto been insignificant may yet add a growing share to the sum of scientific knowledge.

Potash in Yorkshire

POTASSIUM is an element essential to plant growth, and without an abundance of potash fertilisers Britain's intensive agriculture cannot maintain crop production. A supply of potassium is also needed by industry. Britain has had to rely on imports to meet these demands, and hence the prospect that Britain might have buried potash deposits sufficient to meet her needs, a prospect which was suggested by the first results of boring carried out in Yorkshire, aroused considerable excitement.

Before the war nearly all the potash used in Britain came from Germany and France. It derived from rich potash beds that had a common geological origin. According to geologists, all these deposits were laid down when an ancient sea dried up. This sea—known to geologists as the Zechstein Sea—dates back to Permian times, that is, about 30 million years. It extended over much of Central Europe, part of Northern England and part of Northern Ireland. Just before the war a borehole sunk at Aislaby near Whitby struck a potash bed that looked as though it might be part of the Zechstein-Sea deposits. A second one, begun in 1948, revealed beds of potassium minerals at a depth of about 5000 ft.

Prof. C. F. Powell, F.R.S., of Bristol University, awarded this year's Nobel prize for Physics for his research on cosmic rays. (*Elliott & Fry photo.*)

These results created great interest, and made it clear that further investigations were needed to answer two major questions that the exploratory borings had raised—What is the extent of the potash deposits? Can they be mined, or can they be extracted by pumping down water and then pumping out the dissolved minerals?

The lecture which Dr. A. Fleck of I.C.I. gave to the Society of Chemical Industry on October 18th went a long way to answering the first question. An answer to the second question cannot yet be given, though it is fairly clear that to work deposits occurring at twice the depth of the Stassfurt deposits will be a challenge to technical ingenuity.

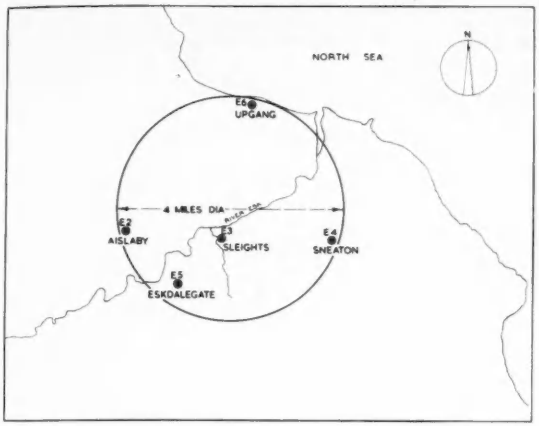
Five boreholes have now been completed in the neighbourhood of Whitby. Each boring has hit two separate beds of sylvinite, which is a mineral composed of sodium chloride and potassium chloride in varying proportions. The upper bed is about 20 ft. thick, and the sylvinite composing it contains 17% of potassium chloride; the thickness of the other bed is 25 ft. and the percentage of potassium chloride in it is 32%. These beds extend over the area of country bounded by the circle on the map. But assuming that they extend only to that line and no further, then these deposits amount to not less than 200 million tons. Which would represent, as Dr. Fleck put it, "a very appreciable addition to the natural resources of the country".

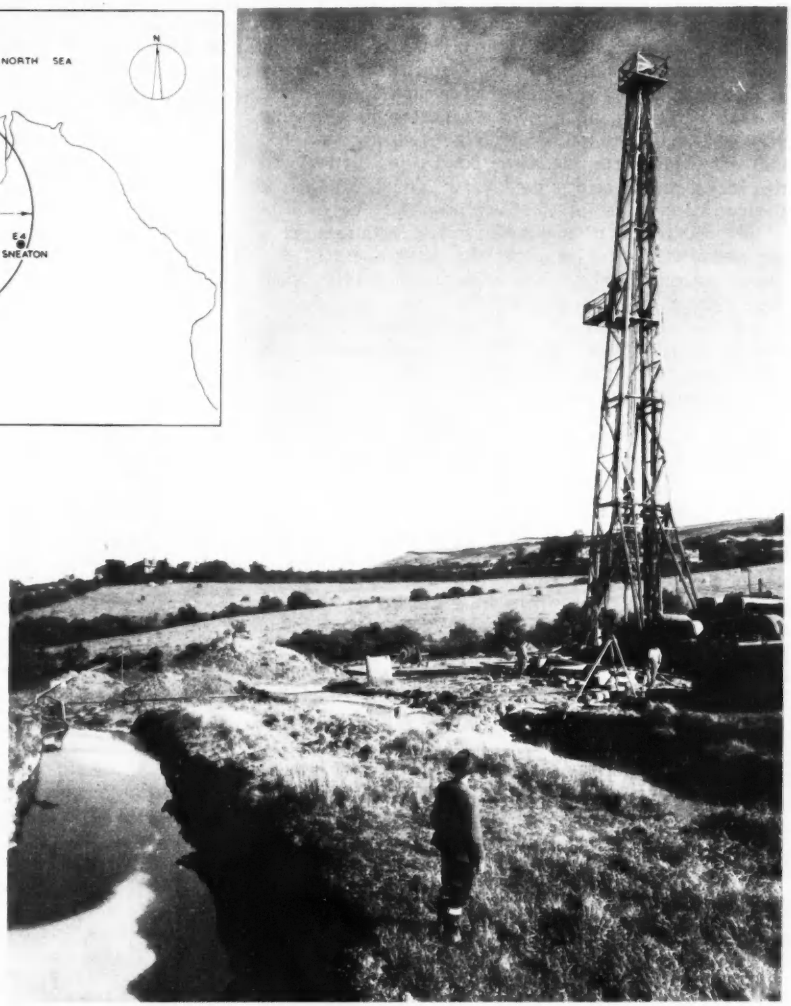
If it should prove possible to extract a third of the potash in these deposits—and experience elsewhere suggests that this proportion should be well within the realms of possibility—there would be enough potash to last Britain 140 years, assuming an annual consumption of half a million tons of potassium chloride a year.

Transmitting Electricity over Long Distances

IN the earliest days of large-scale electrical development, there was bitter controversy as to whether alternating or direct current was the best system for use in the rapidly expanding distribution systems of the country. The battle, of course, was won forty years ago by the A.C. protagonists. But now the use of D.C. in a new form is once again a subject of discussion in electrical engineering circles.

Sir Harold Hartley in his presidential address to this year's British Association meeting mentioned that the development of high voltage D.C. might make possible the transmission of large blocks of power in an economic fashion, for many thousands of miles; and the same eminent scientist, in his capacity as the chairman of the Fourth World Power Conference, also said that the world's power resources are rapidly becoming fully surveyed, a work which has revealed serious limitations in certain directions. Thus the need to carry power from those





DRILLING FOR POTASH

The equipment used in Yorkshire is the drilling equipment standard to the oil industry. To obtain sample cores of the successive rock formations encountered, a hollow drill is used; over 2800 ft. of cores have been taken. The map shows the sites of the boreholes.

regions of the world where there exists either coal, oil, or hydro-electric possibilities, to the centres of population, would become progressively more acute in the years to come. Very great distances on land, and in many cases transmission lines crossing the sea, will ultimately be involved.

Why then is high voltage D.C. of assistance in solving this problem? The basic arguments for use of D.C. may be summarised as follows:

For any transmission link, whether overhead line or cable, there is a limit to the length that can be operated in a stable and economic fashion on a high voltage alternating current system. For overhead schemes, the electrical constants of the line mean that compensating devices must be installed at intervals, and these are expensive and involve many complications. When cable lengths are considered, however—and cables are the only possible method of transmitting power across the sea—the use of high-voltage alternating current becomes entirely impracticable above a certain length. This is because the cable acts as a giant condenser, and the charging current for lines of the order of, say, 100 miles of cable would be so large as to absorb the output of a considerable sized power station for this purpose alone.

Further advantage of D.C. is that for a given insulation, a higher voltage can be used—in fact, 1·63 times the voltage used on A.C. It is also possible to use two conductors only in place of the three needed for A.C. circuits on the normal 3-phase system; further, earth return or sea return can be used under certain circumstances, the link thus needing a single conductor only.

A D.C. transmission system also has advantages in respect of providing a smooth tie between interconnected power systems, since the variations of frequency at one end do not affect the frequency of the system at the remote end. Further, the governing of the power flow is simpler, and the highly expensive and complicated circuit breakers needed on A.C. systems can be dispensed with on simple one-way lines.

How is D.C. transmission carried out? The normal A.C. supplies at the transmitting end of a D.C. link are fed through transformers to large mercury arc rectifiers which have grid control on their anodes in exactly the same way as the thermionic valve widely used in radio applications. A direct current is thus produced, and the given scheme may envisage, say, 100 kilovolts above earth and 100 kilovolts below earth, the centre point being earthed and there consequently being a potential of 200 kilovolts across the two conductors. At the receiving end, the inverter which produces the normal A.C. 50 cycle 3-phase supplies for connexion to the network takes almost exactly the same form as the rectifier. Control of the grids surrounding the anodes of this inverter enables the D.C. power flow to be interrupted at each anode, in such a way as to produce current varying in sine wave form, which can then be taken to a transformer, the secondary of which produces the normal supplies.

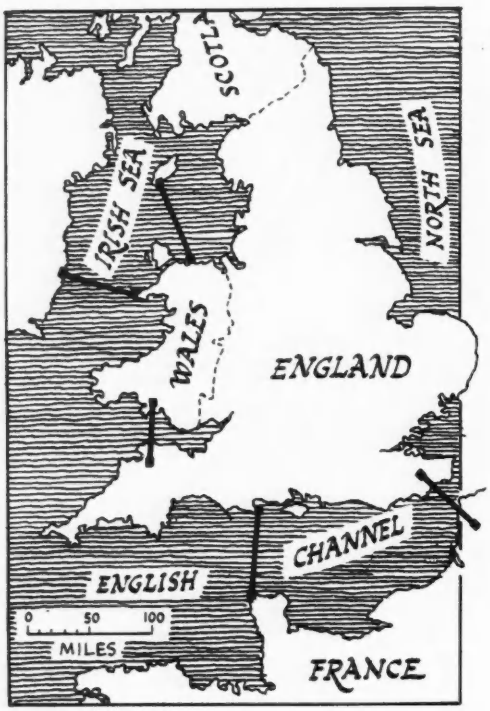
One difficulty which arises at the receiving end is that whereas the demand for reactive power made by the network can be supplied directly from an ordinary alternating current generator, this is not the case with the inverter. Thus, synchronous condensers (which take the form of large synchronous motors whose excitation can be varied) have to be installed to provide the necessary reactive component.

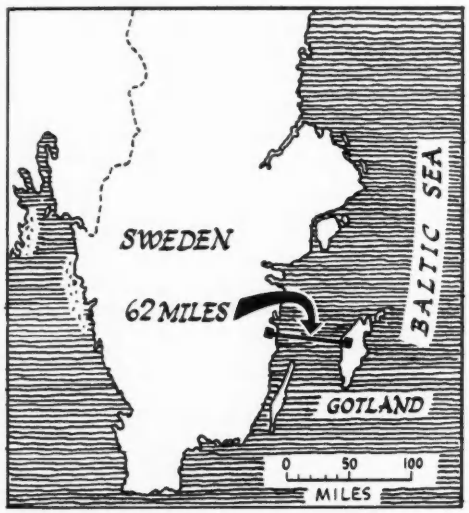
It is estimated that where it is desired to transmit large blocks of power for a distance of between 180 and 360 miles on land, there is a definite case for high voltage D.C. in both the economical and technical senses. Where a sea link is included, the case for D.C. becomes conclusive at much shorter distances of about 20 miles.

The first high-voltage D.C. transmission system in the world is now in the course of construction. Swedish engineers have been very much in the forefront of experimental work in this direction, and when the power supply on the Island of Gotland (which is separated from the mainland of Sweden by some sixty miles of sea), required reinforcement it was decided, this year, to install a high-voltage D.C. cable link from the mainland. The link is to operate at 100,000 volts with a single cable, the sea water and the earth being used as the return conductor. The current will be 200 amperes, thus providing a 20,000 kilowatt feed. The sea-and-earth return, while economical and practicable in this particular case, has limitations (which may be overcome in the future) for general use on land, since the return currents may cause difficulties with telephone cables, water pipes and the like, which lie along the route taken by the current between the two terminal points.

The Gotland scheme, which it is hoped will be in operation in about three years' time, is so planned that when experience has been gained in its operation (and as the load grows on the Island of Gotland) the cable and converter equipment will be duplicated, so that the transmission capacity is increased to 40,000 kilowatts. When this is done one cable will be positive and the other negative, thus abolishing the return circuit through the sea.

It is interesting to note that the Swedish engineers are confident that in spite of the cost of the rectifiers and inverters and of the cable, the price of the unit of electricity delivered to Gotland in this way from the hydro-power systems of Sweden will be cheaper than that of a unit produced locally at a steam power station from imported coal.





The diagram shows the Swedish D.C. link, now in course of construction; and, to the same scale, a link of the same length as it might be used in connexion with the British Grid.

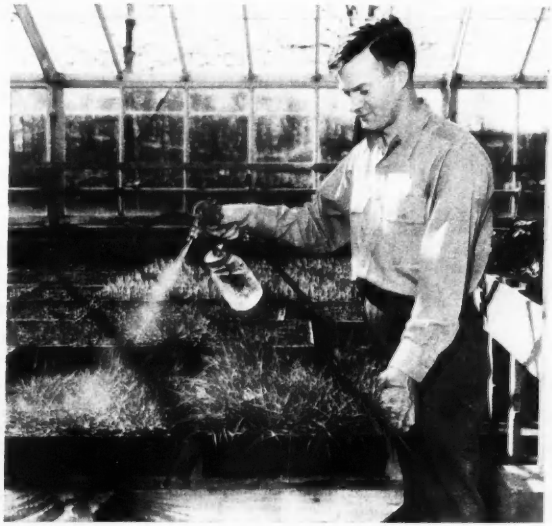


FIG. 1 (*left*).—The grass on the left was sprayed with maleic hydrazide 2½ weeks before the photograph was taken. FIG. 2 (*right*) shows maleic hydrazide being sprayed on lawn grass for tests at the United States Rubber Co.'s laboratories. Besides slowing growth the chemical promises to be a selective weedkiller.

Maleic Hydrazide

AN ALL-PURPOSE PLANT GROWTH-REGULATOR

Prof. DAVID G. WHITE

WEEDS and frequent mowing are the two big headaches in keeping a neat lawn. Wouldn't it be convenient to have a preparation that would kill the weeds and at the same time keep the lawn grasses from growing so fast? For many years this has been a dream of gardeners, but in the not too distant future it may be a reality. This feat and others equally remarkable are thought to be possible since scientists have completed preliminary experiments with the chemical called maleic hydrazide. Besides killing weeds and slowing the growth of desirable grasses this material, developed just over a year ago by the United States Rubber Co., has also been found to slow up the growth of hedges, meaning less clipping for the gardener. On strawberries and raspberries it will delay flowering, eliminating danger of injury from late frosts and also extending the usually short picking season. Tree fruits are also under close study, for if the blossoming and fruiting of apples and peaches can be retarded it would mean a saving of many thousands of dollars yearly lost to late frost each spring.

Maleic hydrazide is still in the early experimental stage, and is not generally available. As a matter of fact, it may never be, because by the time all experiments are completed newer, better and safer substances may be in the process of development. One important point that has not yet been settled, for instance, is how often it can be used without causing injury to various desirable plants.

The possibility of such a material as maleic hydrazide actually arose out of work on auxins, the complex organic compounds found in plants that are now described simply as 'growth regulators'. Most gardeners are already familiar with certain growth regulators and their use as weed-killers, root promoting compounds, stop-drop sprays for apples, sprays to increase the set of tomatoes, and in some cases as treatments resulting in seedless fruit.

First news of this new material which promises even broader application came from the United States Rubber Co's. experimental laboratory in Bethany, Connecticut. Here Drs. D. L. Schoene and O. L. Hoffman sprayed tomato plants in a greenhouse with various concentrations of maleic hydrazide. The plants stopped growing for two months, and then started growing again as vigorously as the non-treated plants. It appeared that they were able to make plants stop growing and start again almost at will.

After seeing how it stopped the growth of tomato plants, the two scientists decided to treat some turf plots to see if the same thing would happen to grass plants. They applied maleic hydrazide to various plots at rates of 8, 4, 2, and 1 lb. per acre. Where the grass was treated with 1 lb. of maleic hydrazide the growth of the plants was slowed up only slightly; at the 2-lb rate, growth stopped for one to two weeks; at the 4-lb. rate, for about four weeks, and at the 8-lb rate, for over two months, at which time all growth was stopped by cold weather. After this quiescent period the growth continued in a normal way.

Then Dr. John W. Zukel tried this new material on weed grasses. Both young and mature crabgrass* plants were

* The specific names of this and other weed grasses mentioned in this article are as follows: Crab grass, *Syntherisma sanguinale*; Johnson grass, *Holcus halapensis*; Witch grass, *Panicum capillare*; Nut grass, *Cyperus esculentus*; Water grass, *Paspalum dilatatum*.

FIG. 3 (*top*).—This photograph was taken 11 weeks after spraying six-inch tomato plants with maleic hydrazide. On the left is the untreated control. The others were treated with solutions of strength varying from 625 to 2500 parts per million (extreme right).

FIG. 4.—The pot-grown couch grass (twitch) on the left shows the effect of maleic hydrazide on growth. It was sprayed with ·25% solution 11 weeks before photograph was taken. Plant on right was untreated; both were originally the same size.

All pictures are reproduced by courtesy of U.S. Rubber Co. and "Flower Grower".

treated. On the young plants the leaves became red and the plants died; older plants were stunted and the leaves remained green, but no seeds were produced. Other weed grasses, including Johnson grass, witch grass, nut grass and water grass, all reacted in a similar manner. Some of these are serious problems to southern cotton growers.

Seven weeks after planting, Green Mountain potatoes also were sprayed with maleic hydrazide. There was no difference in growth or yields between the treated and non-treated plants. But in storage the tubers from treated plants failed to produce sprouts after five weeks at room temperature, whereas those from the non-treated plants had numerous sprouts. This, then, led the scientists to feel that sprouting could be inhibited also on onions and other vegetables.

In California the work with maleic hydrazide was directed toward checking growth of shrubs. An experiment was tried on a pyracantha hedge, and again it checked the plants in proportion to the concentration used, thereby eliminating a great deal of clipping. This was welcomed on the pyracantha as continual clipping throughout the season reduces flower and fruit formation.

Our own work with maleic hydrazide was in still another direction. For several years we have been looking for something that would delay the blossoming of fruits. Anyone who has a lone fruit tree in his backyard—still more so a commercial grower with hundreds of trees—worries through the spring season hoping the fruit will escape cold damage. All too often the flowers and tiny fruits are nipped severely, resulting in enormous losses to the industry and increased fruit prices for the housewife.

The most effective way of avoiding cold injury in the spring would be by some means of retarding the blossoming. Plant breeders have contributed toward this end by developing varieties which reach full bloom several days later than usual varieties. Quite often a delay of a few days is sufficient to escape the danger of killing temperatures, but some means of retarding blossoming for two weeks, or possibly longer, is definitely needed.

Using growth regulators to delay blossoming is not new. About twelve years ago other workers sprayed peaches in the early spring with a weak solution of naphthaleneactic acid, and found that this material delayed blossoming. Unfortunately, this treatment was not practical; it only retarded flowering for a few days at the most, and also resulted in injury to the leaves and young shoots.

A new hope was raised last year when maleic hydrazide was first announced. As is sometimes done, samples of the chemical were sent to investigators in various public experiment stations for further trial. The day after we received a sample, water solutions ranging in concentration from 0·1 to 0·4% were prepared and sprayed on different kinds of fruits. The flowers of peach, sour cherry, gooseberry and blueberry were already open so there was no opportunity to study them. The flowers of apples were already showing pink and the spray did not retard their opening. As a matter of fact, all the flowers fell off two or three weeks later, which was rather discouraging at the time.

We had better luck on strawberry plants which had many flowers formed but not yet open. The flowers which were already formed proceeded to open, but as the days passed no new flowers formed as they did on non-treated plants. Three or four weeks later the sprayed plants resumed flowering and appeared to be unharmed by the lower concentrations of maleic hydrazide. These results were very promising and indicated that total flower development might have been retarded two or three weeks if the plants had been sprayed earlier.

Outstanding results in 1949 occurred with the black raspberry. The fruits of this plant are borne on lateral shoots arising from the previous season's canes. Plants were sprayed with various dilutions of maleic hydrazide before the leaves were fully expanded—only about the size of a fingernail—and before flower buds were visible. The treatments soon resulted in a temporary stoppage of growth. For three or four weeks the leaves and shoots stood still, so to speak, without showing signs of injury. After this quiescent period, growth resumed and the plants had an abundance of flowers and a heavy set of fruit. The fruit enlarged and matured quite normally. Soon after the berries were harvested the growth of the treated plants caught up with that of the check plants. This was probably the first time that fruit blossoming had been retarded without any apparent injury to the plant.

Tree fruits still represent a problem which no doubt will eventually be solved. Strawberries and raspberries conveniently have their leaves available for spraying prior to flowering, but most tree fruits come into flower and leaf nearly at the same time. The problem is complicated by the fact that the flowers of apples and pears start forming almost a year before they unfold. This differentiation or change in the kind of cells within the bud usually starts about June, and additional flower parts are developed thereafter until the time of blossoming. Flowers of the peach are formed on one-year-old shoots and the change in cells generally starts a little later in the summer than with apples. Somewhat similar flower bud differentiation occurs in almost all tree fruits and also in some small fruits. Nevertheless, with most fruits there are several months available for treatments that might delay the time of blossoming because the flowers require six to eleven months to differentiate completely.

With tree fruits, therefore, treatments must be applied under entirely different circumstances. The fact that tree fruits start flower bud development the previous summer offers the possibility that spraying then might retard blossoming the following spring. Last summer we sprayed different fruits to see the possible effect this year. We also injected dilute solutions of maleic hydrazide into the limbs just prior to leaf fall last autumn. A third possibility we have been investigating is application of the chemical in dormant sprays, hoping that the growth regulator will soak through the bud scales and retard their opening.

On the face of the results so far, it seems safe to predict that within the next few years research men will have worked out some practical method of delaying blossoming. The fact that maleic hydrazide has proved successful with the black raspberry opens a new field. There are probably quite a number of similar growth-regulating substances which can be synthesised and tested. Also, the combined results of investigations in various public institutions and industry may come upon a combination of materials that will reduce many heavy chores of gardening as well as side-step expensive frost damage to fruits.

This article is published by arrangement with the U.S. journal "Flower Grower".

As weapons of biological warfare have never been used in actual war they are still an unknown quantity from the military point of view. In the absence of authoritative opinions about their effectiveness rumour has grown till today many have come to regard them as the ultimate in strategic weapons, outmoding even the atomic bomb. If all the relevant facts that are confined within the covers of highly secret dossiers were published, a very different picture of the potentialities of biological warfare might emerge. In this article Chapman Pincher has collated all the facts that are available and attempts an assessment of the decisiveness of biological weapons.

Biological Warfare

CHAPMAN PINCHER, B.Sc.

BIOLOGICAL WARFARE comprises the use in war of bacteria, viruses, fungi and other pathogenic organisms, plus any products of these organisms which can injure people, animals or crops. It cannot be clearly differentiated from Chemical Warfare because some of the products of organisms which might be effective as weapons may be made synthetically.

On the potentialities of Bacterial Warfare—B.W. for short—there is considerable misunderstanding due, not so much to 'popular' misrepresentation as to statements made by prominent people who ought to be better informed. For example, a few months ago Dr. Brock Chisholm, chief of the World Health Organisation, announced that the atomic bomb had been made obsolete by a biological product, only seven ounces of which would be enough to wipe out the human race if properly distributed.

Such a statement had little more significance than saying that the population of Britain could all be killed by a truck-load of cyanide. The degree of success with which Dr. Chisholm's cataclysmic agent—apparently botulinus toxin —could be administered is all important to the argument. And it does not seem that such organic compounds could be used successfully for poisoning food and public water supplies on a big scale.

However, when it is remembered that more people died from influenza in the 1918 epidemic than were killed during World War I the military potentialities of bacteria become formidable.

Any weapon which offers would-be aggressors the theoretical possibility of putting a nation out of action without damaging its factories and cities is a tempting one. Especially is this so when the cost of making such a weapon is very much less than the cost of atomic bombs, and the plant required could quickly be put up by adapting existing commercial installations. (The modern type of Royal Ordnance Factory with its many separate, self-contained buildings, which can be quickly sealed off in case of accident, is easily convertible for the mass production of bacterial agents.)

Unfortunately, so much of the experimental work which has been done on B.W. is covered by security that it is difficult to make a precise evaluation of its potentialities. And there is little reliable evidence from its actual use in the field. Still, enough data are available for a tentative assessment which will dispel some of the emotional fog surrounding the concept of B.W. In my view the best way of setting about this is to list the main known facts:

A protocol prohibiting the use of bacteria in warfare was ratified by many countries including Germany at the Geneva Conference of 1925. British Intelligence knew that Nazi Germany was nevertheless conducting B.W. experiments, but mainly for reasons of manpower shortage little B.W. work was done in Britain even during the war. The United States made a considerable effort in this direction however. This was prompted initially by intelligence reports of Japanese preparations. But British alarm at the B.W. threat following the fall of France was a greater incentive.

Results of the restricted British research were handed over to the U.S.A., and a working collaboration was established, the British and Canadian governments being kept fully informed of American developments.

According to an official U.S. intelligence report there is no evidence that the Japanese Army ever used bacterial weapons, but the Soviet Government has recently published a 535-page account of the trial of 12 Japanese officers accused of preparing and using germ weapons. According to the indictment, a research station with a staff of 2000—150 were bacteriologists—was built near Harbin in Manchuria during 1936; big-scale production of bubonic plague, typhus, anthrax, and cholera organisms was started, fleas to serve as intermediate hosts were bred in incubators, and it is claimed that a successful epidemic of plague was produced experimentally in China in 1942.

Considerable details of the Allied wartime effort were disclosed by a report (the Merck Report) published from Washington early in 1946 and hurriedly withdrawn a little later. These reveal that following the British representations American B.W. research was stepped up and taken over by the U.S. Army Chemical Warfare Service. Large laboratories and pilot-plants were set up at Camp Detrick, near Frederick in Maryland, and were soon in operation. Some idea of the size of the project is shown by the fact that at the height of its wartime development about 3900 people were involved in it. Field-testing stations were set up in Utah and Mississippi. A further big pilot-scale plant was built in Indiana. The U.S. Navy had its own germ-warfare project located at the University of California. Cost of the whole U.S. project was put at about $50,000,000. Research was carried out along five main lines: (1) Development of methods and facilities for the mass production of micro-organisms and their products; (2) Experiments on methods of increasing the virulence of such organisms; (3) Field experiments involving the use of animals on the dissemination of bacteria and bacterial products; (4) Development of methods for the rapid detection of minute quantities of disease-producing agents; (5) Defensive measures, chief of which were methods of

protecting water and food supplies; and the mass-production of protective vaccines. (Such rigorous precautions were taken against accidental infections in the plants themselves that there were only 60 cases, none of which proved fatal. Full use was made of these and other naturally occurring cases to test out new chemotherapeutic measures and immunisation procedures.)

The most spectacular of the published wartime developments was the preparation of pure crystalline bacterial toxins. Information released from Camp Detrick in 1946 gave full details for the preparation "in five-gallon carboys" of pure crystalline toxin from the bacterium (*Clostridium botulinum*) responsible for botulism—a rare but very dangerous form of meat-poisoning. It proved to be the most potent toxic material reported up to that time—the minimum lethal dose for a man being about 1/700th of a milligram.

Details of highly successful experiments on the production of compounds which could be sprayed from the air to kill growing crops were also released. Best known of these compounds are the so-called 'growth hormones' now being widely used as weed-killers. These substances are really synthetic imitations of the growth-promoting substances produced by plants. An overdose of them provided as a spray given at a rate of a couple of pounds per acre makes the plants grow so rapidly that they die. Some act mainly on the broad-leaved plants e.g. cabbages, turnips, potatoes. But one group is effective against barley and oats, and no doubt forms which can kill wheat will be discovered. It was, incidentally, in this connection that the Americans came nearest to initiating biological warfare during World War II—as the war ended a shipment of synthetic hormones was on its way to the Pacific for use against the rice crop in the Japanese homeland.

Since the war B.W. work has been continued in America at fair pressure, but at nothing approaching the tempo of atomic weapon research.

Immediately after the war the British Government set up a bacterial warfare establishment—called the Microbiological Research Department—as an offshoot of the Chemical Defence Research Department at Porton, on Salisbury Plain. Dr. D. W. Henderson was put in charge of the station which was a makeshift arrangement of huts. Bacteriologists from non-Government laboratories, and occasionally from abroad, have been allowed to work in certain non-secret departments of the establishment.

Within the last two years a huge new establishment has been built close by. From the size of the high-windowed building as seen from the main road it must be the biggest science building in Britain. A pilot plant for the production of antibiotics is being built in conjunction with it.

From staff advertisements which have appeared repeatedly it is clear that the Government is having considerable difficulty in getting doctors, bacteriologists, and veterinary surgeons to work on bacterial warfare in either its offensive or defensive aspects. The relatively low salaries offered have not helped. £960 a year for a 35-year-old medical researcher may be sufficient inducement to a doctor to work in a hospital laboratory, but not, apparently, in an establishment where the ultimate object is destruction of life. The Americans have experienced exactly the same difficulty.

The fact that advertisements for microbiologists to work in the War Office have appeared in the technical press recently suggests that the British B.W. work is reaching the experimental weapons production stage.

Naturally little about the post-war work carried out either in Britain or America has been published, but such titles as have appeared give a fair indication of the direction in which research is being pursued. Examples: *Experimental Air-borne Infection*—a book by Theodor Rosebury, wartime chief of Camp Detrick's "Air-borne Infection Project", "described new and safe methods for the study of air-borne clouds of highly infective agents", as the publisher's blurb says; "The purification and crystallisation of botulinus toxin" (*Science*); "Studies on tularaemia" (*Journal of Immunology*).

According to the latest published report U.S. naval bacteriologists are using the radioactive tracer technique to discover how bacteria are distributed within the body tissues following deliberate airborne infection.

Mice were exposed to aerosols of pneumonic plague bacteria previously made radioactive by growth in a medium containing radioactive phosphorus. Within a few minutes of exposure the mice were sacrificed and dissected so that the various tissues could be reduced to ash. The radioactivity strength of the ash samples as measured by a Geiger counter gave an indirect measure of the uptake of the bacteria by the different tissues. The first experiments showed that the animals retained practically all the bacteria they inhaled. About 30% of the germs remained in the respiratory organs. The rest got into the alimentary canal.

Odd reports, such as a preliminary statement that streptomycin is probably an effective treatment for pneumonic plague, have been issued by the British B.W. establishment. This particular report, which was published in 1947 before security became as tight as it is now, gave details of a machine designed at Porton to produce pneumonic plague aerosols for the infection of experimental animals. The report also revealed that the British researchers were still working in close collaboration with the American biologists at Camp Detrick.

So far experiments seem to have established that more than a score of disease agents might be worthy of trial in active warfare. Of these the most important seem to be the organisms responsible for: anthrax; tularaemia (rabbit fever); brucellosis (undulant fever); psittacosis (parrot fever); pneumonic plague, which unlike its bubonic counterpart does not need an intermediate host but can attack the human lungs directly by the airborne route: melioidosis—a tropical disease like glanders; and haemolytic streptococci—blood-poisoning germs.

Research aimed at developing particularly virulent strains of these agents—by deliberately producing mutations as a result of X-ray bombardment, etc.—have been successful. For example, a recent American paper reported how by exposing *Staphylococcus aureus* culture to ultraviolet light, strains resistant to penicillin and streptomycin could be induced. The virulence of certain agents has been so enhanced that they can infect man directly thereby removing the need for an intermediate host. That this was possible has been known since 1931 when a new strain of yellow fever virus which will affect man directly through the lungs instead of being transmitted by mosquitoes was reported.

At the same time the virulence of certain other agents has been reduced to produce strains which no longer kill but cause transient sickness sufficient to reduce an infected population's will to resist long enough for them to be overcome by occupying forces. A germ attack producing 10,000 sick people needing immediate medical care to prevent further spread of infection might create a greater defence problem than 10,000 dead.

Three main methods of spreading bacteria and viruses are being considered:

(1) Large-scale infection of drinking waters either from aircraft or by agents.

(2) Germ-laden aerosol mists established from short range by shells or by modified gas-projectors.

(3) Infective aerosols established from long range by aircraft or rockets.

The first is unlikely to be effective on a large scale. It could not be successfully applied to reservoirs as the normal filtering apparatus would probably remove the germs. This fact was forcibly demonstrated by the cholera epidemic at Hamburg in 1892. There were 17,000 cases and nearly 9000 deaths within two months. Hamburg did not filter its drinking water; the nearby city of Altona, which did, escaped the epidemic.

The second method does not seem to be practicable because of the danger of blow-back through wind changes.

Method No. 3 seems to be the most suitable. The latest information available to me shows that a practicable long-range bacterial warfare weapon which could be put into operational use if required has been devised in the U.S. It is a cluster-bomb made up of 4 lb. canisters each containing a few cubic centimetres of concentrated germ culture. Dropped from a high-flying aircraft, the bomb would scatter the canisters at any required height much as incendiary bombs were scattered. Each canister is fitted with an impact or barometric fuse actuating a small opening charge.

Field trials carried out in Utah show that a significant proportion of the bacteria survive the heat and blast of the opening charge. Eventually about 10% of the original culture gets scattered in aerosol form.

By testing the bomb over an area laid out with culture plates, and by experiments on animals the U.S. scientists have calculated that about four tons of such canisters would effectively contaminate about one square mile of battlefield. About 50% of any troops there not adequately protected might be infected. A similar bomb-load exploded over a built-up area would contaminate about half a square mile infecting perhaps 1000 people.

Such a weapon which would seem to possess powerful 'terror' value would be attractive for attempts at reducing strong points and distant industrial targets not requiring immediate occupation.

There is evidence, too, that experiments on the deliberate spreading of crop pests like wheat rusts and leaf-spot disease of rubber have been partially successful.

As with every weapon there are operational shortcomings associated with B.W. Whereas with an atomic bomb it is possible to make a reasonably accurate assessment of casualties, field commanders could never accurately anticipate the effects of germ weapons. So much must always depend on indeterminable factors like local wind conditions, temperature and above all the susceptibility of the population being attacked. Medical authorities can never be sure when a disease will become epidemic. Sometimes when conditions seem favourable for a local outbreak to develop into an epidemic it fizzles out. These chance factors are, of course, enormously increased when one or more intermediate hosts have to be used as in the case of the tick-borne fevers and bubonic plague which is transmitted by rat fleas.

Attempts to destroy rabbits in Australia by starting up an epidemic of virus myxomatosum failed completely. This experience has been reinforced, I understand, by American field experiments aimed at producing epidemics to order among experimental animals.

The greatest theoretical drawback to germ weapons, therefore, would seem to be their unreliability. No commander would dare to plan an assault on the assumption that a target which had been germ-bombed must be sufficiently softened, that is unless he had really up-to-the-minute intelligence.

This difficulty of starting epidemics to order is, of course, more than matched by the difficulty of counteracting them. The danger of a boomerang effect seems so great under present conditions of knowledge that it seems most unlikely that germs capable of starting epidemics would be used. This contention is supported by reports that U.S. defence authorities have restricted the species of germs short-listed for use to those which infect individuals, but are not easily passed on from person to person.

It is possible that epidemics could be risked in strong points which do not have to be immediately occupied or in isolated areas which could be captured by shock troops specially immunised against the particular disease. But anyone aware from first-hand experience of all the things that can go wrong in battle will see that such measures, though they may sound fine on paper, would be chancy in practice.

Without doubt the best basic defence against B.W. is efficient sanitation coupled with a high standard of personal cleanliness throughout the community. So long as such elementary precautions could be maintained during war the deliberate spreading of diseases like cholera, typhoid and bubonic plague would be extremely difficult. The custom of routine inoculation and vaccination of children effectively reduces the danger from other epidemic diseases such as diphtheria and smallpox.

The increasing production of antibiotics and their general sale in chemists' shops has also greatly weakened the potentialities of germ attacks. Some of these antibiotics are powerful antidotes to the normally rare germs which might be used as weapons—pneumonic plague, for instance, can be successfully treated with streptomycin. However, it must be admitted that little in the way of chemotherapeutic defence against viruses is available.

The standard respirator or even something as simple as a surgeon's mask clearly offers considerable protection against many infections which might be spread deliberately. But no practicable civilian respirator could provide protection against all of them.

To sum up then, it is clear that germ weapons constitute a powerful threat demanding rigorous defence preparations, but there is little foundation for wild claims that they are super-weapons outdating the atomic bomb and capable of deciding wars overnight.

FIG. 1.—Two convection clouds in different stages of development. In front is seen a towering cumulus; behind, a fully developed cumulonimbus with anvil of false cirrus (ice) spreading out.
(*Photo by F. H. Ludham*).

The Thunderstorm: A Natural Dynamo

Prof. P. A. SHEPPARD, B.Sc., F.Inst.P.

THE atmosphere presents us with many awe-inspiring phenomena, few more impressive than a thunderstorm. It has provided scientific man with a challenge which he has taken up with avidity since the time of Benjamin Franklin and D'Alibard in the mid-eighteenth century. And today he is still trying to discover the actual *processes* which give rise to the lightning flash and the resulting thunder. In this search he has made some progress in recent years.

In this survey we shall first describe the thundercloud as cloud, that is as a volume of air containing water droplets, ice crystals and, in the mature stage, rain, snow and hail. This aspect is indeed all-important since the thunder is a consequence of a particular cloud structure. We shall then go on to describe its electrical behaviour and the way in which cloud voltages may perhaps be generated. And finally we shall examine the thundercloud as an atmospheric dynamo responsible for electrical effects not merely in its neighbourhood but over all the fine-weather regions of the earth.

The Formation of Thunderclouds

On a warm summer day or in a northerly air stream from the sea in any season—in conditions in fact in which the lower atmosphere is abnormally warm and moist relative to the air some kilometres aloft—convection sets in. This convection manifests itself initially as cumulus cloud which is formed in the rising streams of air cooled to below the dew point by their expansion against the steadily decreasing pressure of the surrounding atmosphere. If the instability is great the cumulus will grow to great heights (see Fig. 1), with 'fingers' continually thrusting upwards from the top of the cloud—veritable fountains of air which constitute the convection. A stage is ultimately reached when, by processes which are not yet clearly understood but are discussed later, the small water droplets composing the cloud are caused to aggregate into much larger elements—probably small hail. These fall with respect to the rising air, but not necessarily with respect to the ground, growing meanwhile by 'sweeping' up the cloud droplets in their paths. The uprising current becomes thereby a means for the collection of a vast amount of liquid (or solid) water, which is fed into the base of the system continuously as vapour while the upward current is maintained. The collector is, however, self-destroying for the weight of water suspended in a vertical column becomes ultimately so great that it is able to kill the up-current that gave it birth. Indeed it sets off a reverse, downward current; the precipitation, often torrential, is released; lightning is now most liable to occur, and the cloud then gradually passes into a stage of decay. It is then that the characteristic anvil top

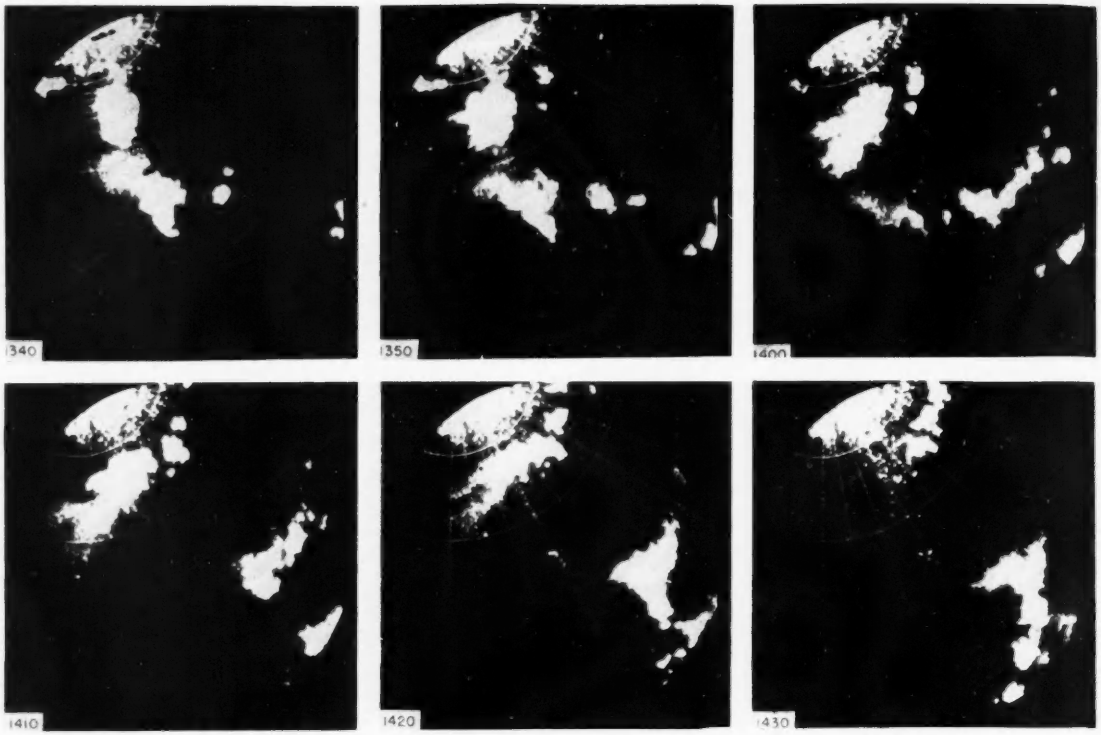


FIG. 2.—Radar views at 10-minute intervals over 50 minutes, of cumulonimbus clouds forming, moving and decaying. The radar presentation is by Plan Position Indicator; the presentation is off-centre, the radar station being in top left-hand corner, with range circles at 10-mile intervals. Note the initial growth and later decay of a cloud system 10–20 minutes S. to SSE. of the radar station and of the sustained growth of an initially smaller, two-echo system 30 minutes S.E. of the station. (*After Byers*, 1949.)

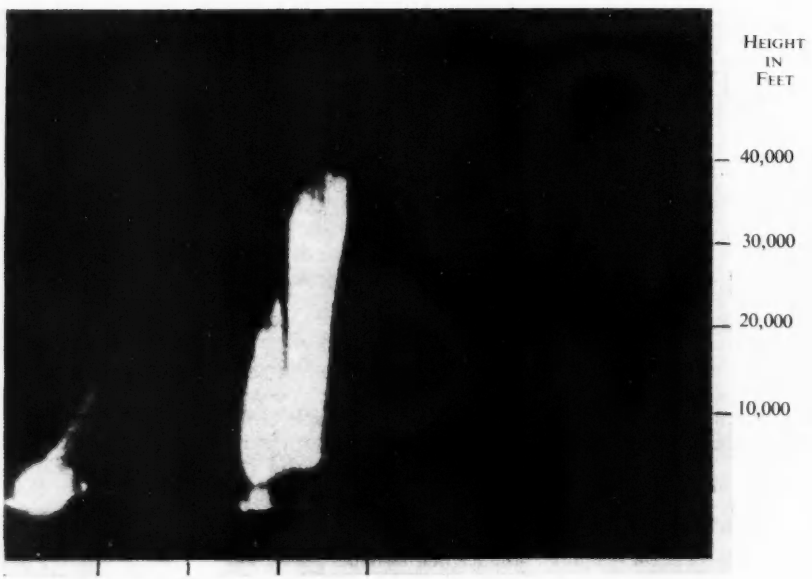


FIG. 3.—A radar echo of a thunderstorm on a range-height indicator, which shows vertical as well as horizontal development. The nearer column was probably a newly developing cloud at the edge of a more mature cloud in which a large amount of ice, sufficient for echo production, was present at nearly 40,000 ft. where the temperature was about −70° F. (*From R. F. Jones, 1950, by courtesy of the Royal Meteorological Society.*)

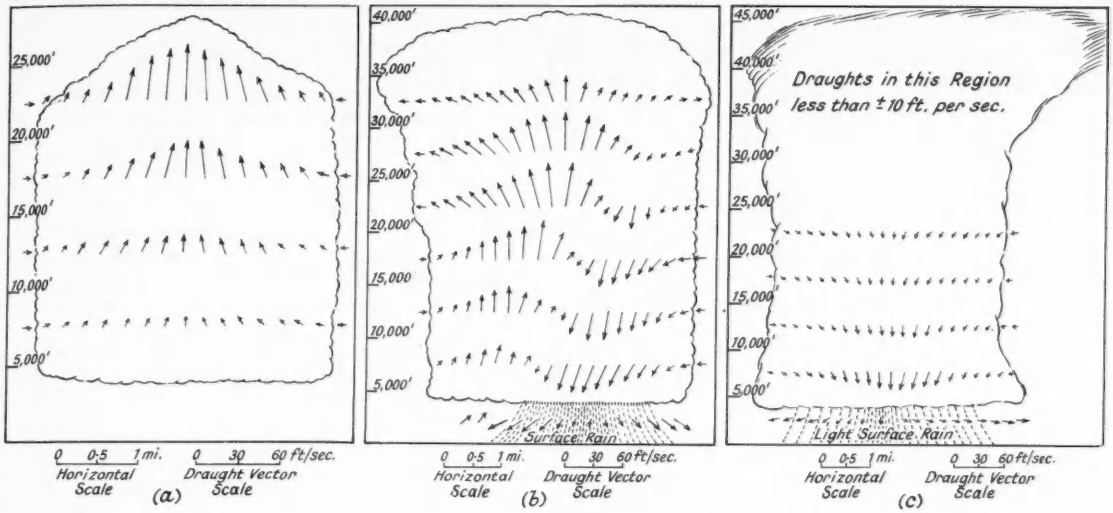


FIG. 4.— The air-current system within a single cumulonimbus cell in (*a*) growth (Cumulus) stage; (*b*) mature (heavy rain) stage; (*c*) decay (anvil) stage. The lengths of the arrows are proportional to the speed of the up-draughts or down-draughts within and below the cloud, according to the 'draught vector scale' shown beneath each section. (*After Byers and Brahm, 1948; reproduced by courtesy of the editor of "Science Progress".*)

of the thundercloud (*cumulo-nimbus*) becomes dominant (see Fig. 1). This anvil is composed almost entirely of ice particles (so-called *false cirrus*) and it may be largely responsible, by processes discussed below, for the rather steady but only moderate rain which frequently follows the initial torrential downpour of rain or hail.

Our understanding of the life history of the thundercloud, as cloud, has been greatly advanced in the post-war years through a large co-operative investigation in the United States, by Byers and his collaborators. They set up a dense network, over an area about ten miles square, in Florida and Ohio, of meteorological ground recorders (rain-gauges, etc), and of pilot balloon and radio wind stations; they also sent up aircraft which flew at between 5000 and 25,000 ft. through the cumulo-nimbus clouds which formed, travelled and dissipated over the network. By these means information was obtained on the magnitude and extent of the vertical currents in the clouds, on the associated horizontal winds, and the pattern of the rain.

They furthermore made use of the new tool, radar, for observing the clouds (and incidentally for tracking the aircraft within them). Radar pulses of sufficiently short wavelength (10 centimetres or less) are reflected by clouds containing liquid water or ice in sufficient density or in sufficiently large-sized particles. Thus the radar disclosed when and in what parts the clouds first created those reservoirs of water we have spoken of above, and something of what happened to them thereafter. Fig. 2 shows a sequence of radar views of clouds passing through development and decay processes which are even more obvious than their travel. Fig. 3 presents a different radar view of a thundercloud.

The picture which has emèrged from these investigations is roughly as follows. The thundercloud consists of one, or more generally, of two or three 'cells', each of which passes through a more or less definite life history of growth, maturity and decay in an hour or so, often triggering another cell nearby during its maturity. Each cell has a diameter of a few kilometres and there is a space of cloud-filled air of about one kilometre between the cells. The three stages in the life history of a cell are shown in Fig. 4 from which it may be seen that upward motion only characterises the growth (cumulus) stage, co-existing upward and downward motion the mature (heavy rain) stage, and gentle descending motion the decay (light rain) stage. The down-draught of the mature stage gives rise to the wind squall and temperature drop at the earth's surface which are characteristic of a thunderstorm. They are primarily due to the partial evaporation of cloud and precipitation and consequent extraction of heat from the air during the descent.

The condensation of water vapour in the rising air takes the form of small water drops, not merely at temperatures above 0° C. but down to as low as −40° C. and a substantial part of a thundercloud is composed of super-cooled droplets. But in the levels where the temperature is below 0° C. some ice crystals are also formed; their abundance relative to the number of water droplets is the greater the lower the temperature, and below −40° C. ice only condenses from the vapour. The physical problems involved in the condensation process, and particularly in the requirements for ice formation, are considerable and the subject of much current research. We do know, however, that a mixed cloud of ice and supercooled water is unstable, and that water vapour distils over from the relatively abundant water droplets to the (initially) rarer ice crystals. The latter therefore grow preferentially and become the germs of precipitation elements.* Once they have reached a size

* The term *precipitation element* is used for a particle which, usually after further growth, may fall out of the cloud either as rain, hail or snow. The majority of water droplets in a cloud are too small to become precipitation elements.

sufficient to cause them to fall at an appreciable rate relative to the water droplets surrounding them, further growth will occur by sweeping. The process is similar to the icing that occurs on an aircraft flying through cloud, and the deposit may similarly be in the form of opaque rime or clear ice (glaze) according to the temperature, the size of the element and the water content of the cloud. Increase in any of these favours clear ice because the latent heat of fusion is then less readily disposed of. Thus the hailstone is to be accounted for in principle. In its riming growth it produces small ice splinters which are available to start new precipitation elements, while in its glazed growth it may perhaps shed water drops sufficiently large to act as further precipitation elements. Here perhaps is the heart of the thunderstorm problem, for both processes are associated with the separation of electricity.

Electrical Behaviour of Thunderclouds

Here we begin with what we know with some certainty and then pass on to the more conjectural. The thundercloud is a mechanism whereby positive and negative charge, originally present in equal amounts (as always in an electrically neutral volume containing matter), becomes separated, the negative charge appearing towards the base of the cloud and the positive towards the top. The cloud is in fact a dynamo with negative and positive terminals near the base and top respectively. This simple picture is complicated by the more or less frequent appearance of a subsidiary volume of positive charge embedded in or slightly below the negative charge near the base. Our picture (see Fig. 5) derives from several lines of work—from the electric field set up by the cloud at the ground, from the sudden *change* of field which occurs at the ground when a lightning flash passes from one pole of the cloud to another or to the ground and, most directly, from sending balloons carrying electric-field recording apparatus into the clouds themselves. This last line of investigation was initiated at Kew Observatory before the war by Simpson and Scrase and continued by Simpson and Robinson.

The outstandingly important result of these balloon flights was the demonstration that the separation of upper positive from lower negative charge took place at least a kilometre above the 0°C. level and therefore in the region of supercooled cloud and growing precipitation elements. When positive charge was observed below the negative it occurred at temperatures above 0°C., so that it is rather unlikely to be associated with the ice phase. The electric-field strength observed within the clouds was of the same order as that below cloud base, much less than the field needed to produce a spark in air. Even so the potential difference between the poles of a cloud is about 100 million volts. It is to be inferred that the field rises to the sparking limit only quite locally, and is perhaps aided in this by the tips of precipitation elements. The latter is suggested by Ross Gunn's recent measurements, from aircraft, of the charge carried by precipitation elements within cumulo-nimbus. He found that the most heavily charged elements would have produced a sparking field at their surface if distorted somewhat from the spherical. Ross Gunn made no measurements of the charge carried by cloud droplets so that the complete picture of charge distribution is not ascertainable from these flights.

Finally, on this topic, we note the phenomena which are in operation to dissipate the charge which is generated by a thundercloud. The most impressive is of course the lightning flash itself, though it is not the only effective cloud discharger. It may pass from the cloud to earth, or internally—a short circuit of the dynamo. (A single flash is in fact a multiple of strokes whose structure has been elaborated in recent years by Schonland and his collaborators in South Africa, see Fig. 6.)

An active thundercloud gives one flash about every 20 seconds (the average current is about 1 amp.), and at this rate the cloud is dissipating electrical energy through lightning alone at an average rate approaching a million kilowatts, spent mainly in the production of heat, radiation (ranging from visible light to radio waves) and sound.

The electrical currents produced by the fall of charged precipitation, which within the cloud lead on the whole to charge separation, provide a second method of charge dissipation when they pass to earth and the rate may amount to nearly 1 amp. for a cloud, though it is highly variable. Another most important source of charge dissipation is the point-discharge current which sets in at pointed objects, such as trees and grass blades whenever the field rises above some critical value for the particular object. This current, known of old as St. Elmo's Fire, partially neutralises the charge aloft to which the field is partly due. Finally, the rather highly conducting upper atmospheric layers above the charged cloud-top provide an ionic leak from the latter.

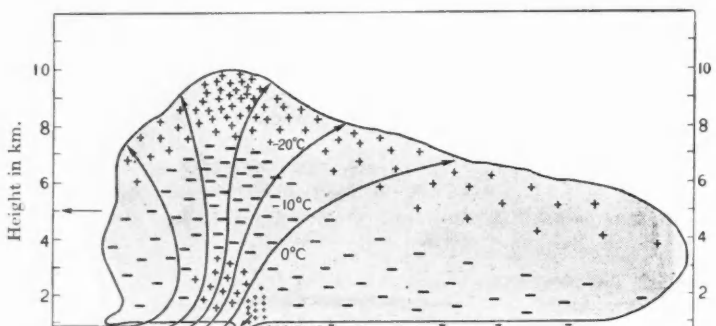


FIG. 5.—Diagram showing air currents and distribution of electricity in a typical thunderstorm, according to Simpson and Scrase, 1937. (*By courtesy of the Royal Society.*)

The outlines of the charge separation and charge dissipation may now be seen as a whole. Charge is separated within and possibly below the cloud until the field locally exceeds the sparking limit and a lightning flash occurs. The charge separation continues and at such a rate that, left to itself, it would recharge the cloud in about five second. The leakage, however, due to rain, point-discharge and natural ionic currents causes the recharging process to take about twenty seconds and a second flash may then occur. It can be hardly an accident that, in single-cell thunderclouds, the first lightning flash, generally internal, coincides roughly with the initial appearance of heavy precipitation.

Theories of Thundercloud Electrification

There have been many theories proposed to explain the electrification of thunderclouds but not one can be said to be generally acceptable. The problem is essentially to find the one or more mechanisms, out of all the numerous mechanisms that seem possible, which will separate charge at the *rate* at which it is observed to be dissipated by the processes mentioned above. It must of course also meet the requirements as to temperature which were inferred from the Kew balloon flights.

We may very briefly review some of the processes which separate charge and which *might* occur on an appreciable scale in a thundercloud. They are:

(i) The positive electrification of water drops when they break up after growing to an unstable size.

(ii*a*) The positive electrification of an ice crystal growing from the vapour, or of a hailstone when growing by rime formation; the corresponding negative charge being carried away on ice splinters.

(ii*b*) The negative electrification of an ice crystal or small hailstone when evaporating and producing splinters.

(iii) The negative electrification of rain and cloud drops and perhaps of ice particles when falling through a positive field in an ionised atmosphere. The reverse effect happens when the field is negative (Fig. 7*a*).

(iv) Frictional electricity (of uncertain sign, but negative according to Simpson), produced on ice crystals during collision.

(v) The negative electrification acquired by water drops and ice crystals in an ionised medium by virtue of the contact potential of 0·25 volt which exists across the surface of the drop or crystal (Fig. 7*b*).

In all cases the downward motion of the larger cloud elements with respect to the smaller, or to the air, provides the consequent spatial separation of charge.

Of the above only the third and fifth processes have received quantitative treatment for conditions at all simulating the interior of a cloud, itself rather uncertain in some important respects, while none can be definitely dismissed as unimportant. Consequently the work of the next few years will be to determine more precisely the constitution of the interior parts of a cumulo-nimbus and to evaluate, experimentally or theoretically, the operation of the above charge-separation processes under realistic conditions. There we must leave the problem of the thundercloud for the present.

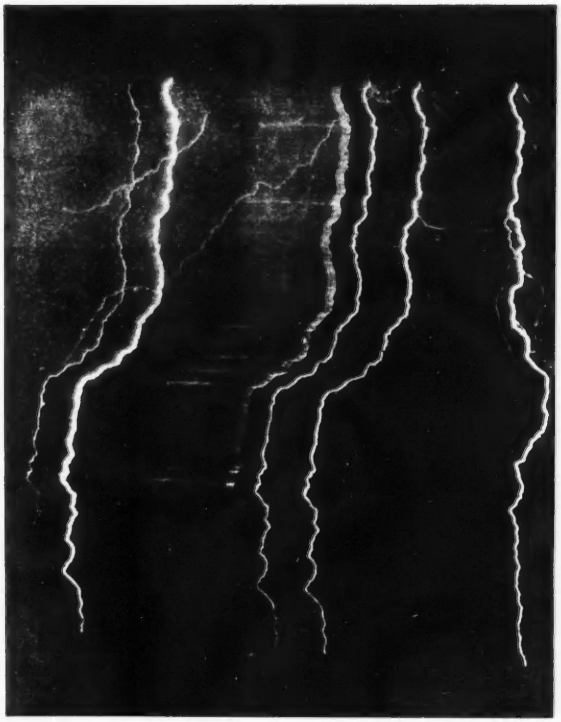


FIG. 6.—A lightning flash, showing the component strokes, taken by means of a rotating camera which was rotated by hand through 120° in about one second. The sequence is from right to left. (*After Walter.*)

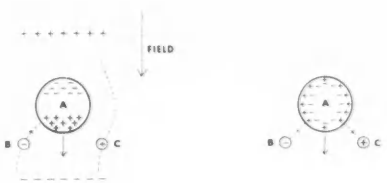


FIG. 7*a* (*left*).—Separation of charge by Wilson influence process. Drop A, falling in a positive field, has positive charge induced on its lower surface and negative on upper. Upward moving negative ion B is attracted and caught by lower face of A while positive ion C, moving downward more slowly than A, is not so caught. A thus acquires negative charge. The opposite would happen if the field were reversed. FIG. 7*b* (*right*).—Separation of charge by contact potential. Initially neutral drop A has surface molecules orientated with positive poles upward. Negative ions B in region of A thus attracted and positive ions C repelled so that A acquires negative charge.

In all regions of the earth outside those of disturbed weather (rain, hail, snow, fog, etc.) there is found to exist an electric field, called the earth's *fine-weather field*, such that the air at a height of 10 metres is about 1000 volts above earth potential. This implies that there is a net free positive charge in the atmosphere. There is a corresponding

[Continued on p. 402

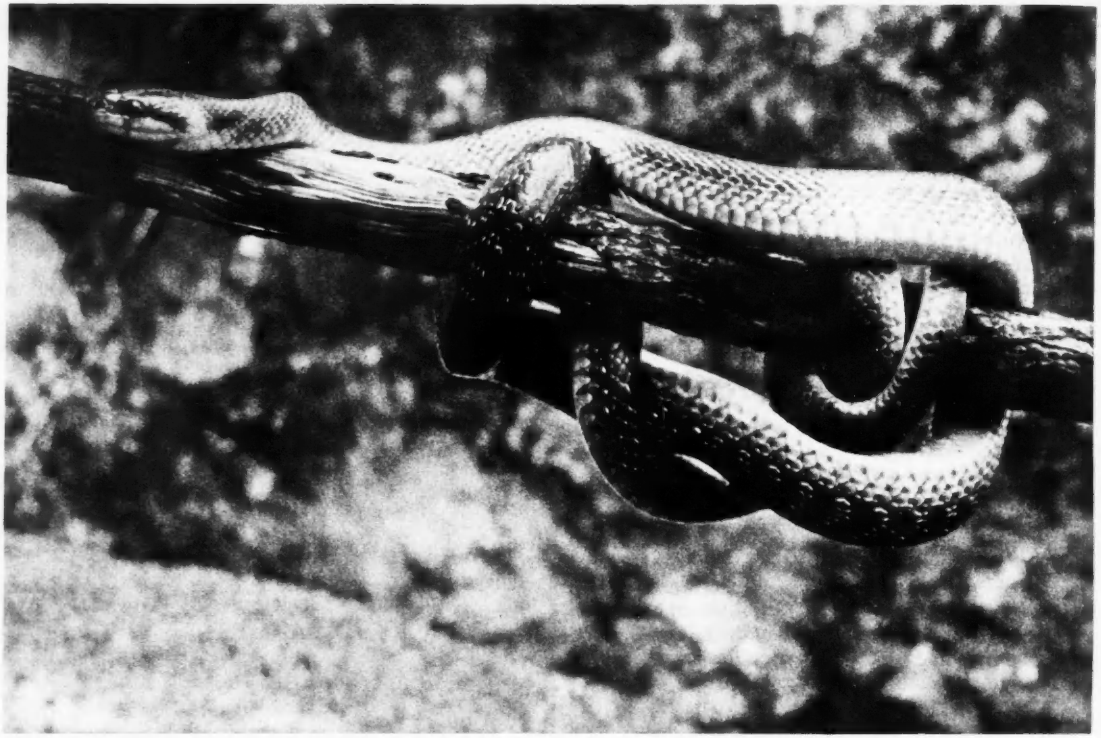


FIG. 1.—The Aesculapian Snake, which is named after Aesculapius, the Greek God of healing. A tree-climbing constrictor, it is at rest along a branch. (This specimen is 3 ft. long, but the species can attain 6 ft.) The keels at the edges of th eventral shields are clearly shown.

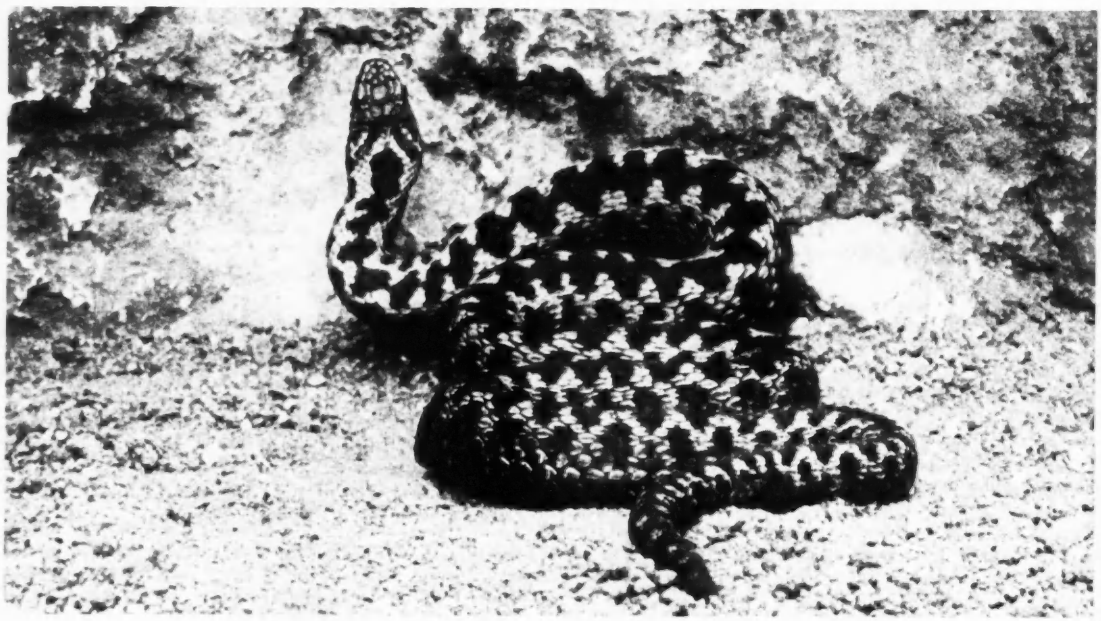


FIG. 2.—Northern Viper or Adder, in a defensive attitude preparatory to striking at an object waved above its head. (*Photo by Lionel Day, F.R.P.S.*).

The Mechanics of Snakes

ALFRED LEUTSCHER, B.Sc., F.Z.S.

A FRIEND of mine once tried to get through the customs a snake which he was bringing back with him from the Continent. Four-footed animals, such as the rabbit and squirrel which he also had with his baggage, were passed by the customs officer without comment. But no matter how my friend attempted to trace the ancestry of his pet in terms of lost legs, it had none just then, so that was that.

That serpents are of quadruped descent is not an easy matter to prove. These limitations were formerly sufficient to link it, even among scientific circles, with other limbless creatures, such as those amphibians with scales in their skins, called Coecilians, and certain limbless lizards like our native slow-worm. There is even no tangible evidence to show that they ever possessed functional limbs.

Snakes have been claimed from Cretaceous rocks, but this is doubtful. Later fossils from the lower Eocene in America approach the lizard type in bone structure. Viper-like snakes are known from the Miocene of France and Germany. More recent snakes from Egypt are boa-like and appear to have been monsters, probably growing to 60 ft. in length. All the above were snakes, that is, without functional limbs.

There is no 'story of the horse' flavour to show for a snake's evolution, which is understandable since the skeletons of these creatures are too delicate and brittle to fossilise well, and the full story of how the snakes evolved may remain forever a secret.

Circumstantial evidence and comparative anatomy of the snake are, however, encouraging. In these respects they are undoubted reptiles which, as a class, are derived from land quadrupeds.

A faint clue to the origin of snakes may be seen in the skeleton of the largest, living species, which are of the more primitive kind. One familiar member of this family (the Boidae), the python, retains a curious relic of the past in the shape of certain bones lying near the base of the tail. They consist of what are thought to be traces of a pelvis and hind limbs. Attached to each femur there is on the surface of the body a conical, claw-like spur. These spurs are larger in the male python and no longer function as limbs, but serve as excitor organs when scraped against the female during the act of mating. We see a somewhat similar parallel in the vestigial hind limbs of certain whales, undoubted mammals which live entirely in water and whose quadruped ancestors are as much a mystery as those of snakes.

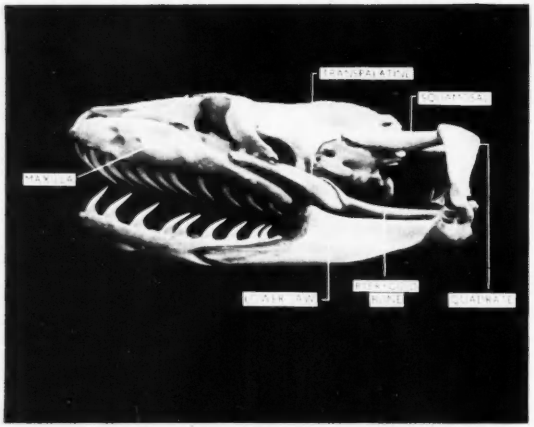
Serpents superficially resemble worms, for which they may be mistaken, but a true worm has no bony jaws, a tongue or well-developed eyes, and is classed with the animals which have no back-bone. The worm-like snakes vary greatly in length, from a 4-in. species like *Glauconia dissimilis* to a 30-ft. giant like the Malay Python (*Python reticulatus*). Their body may be long and slender, or short and fat, according to the species.

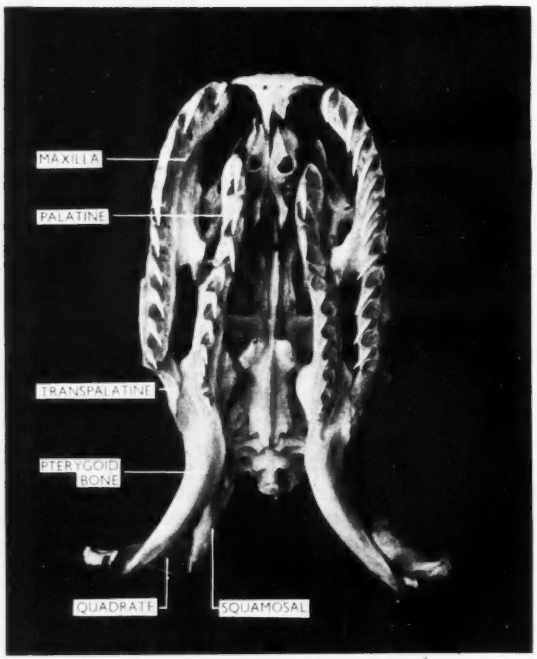
The back-bone of a snake is composed of numerous vertebrae which are of two kinds—those of the body which carry each a pair of ribs, and those of the short tail which have instead long transverse processes. The vertebrae are connected by 'ball-and-socket' joints which allow for great flexibility. At the same time, because of certain projections on each vertebra which lock with the adjacent one in a kind of dovetailed joint, a snake's body possesses a rigidity which is remarkable for such a delicate mechanism. The slightest blow will fracture or dislocate a snake's backbone, yet the animal can twist and rear into positions impossible in other vertebrates. Many a pet snake owes its escape from captivity to the strength and suppleness of its backbone.

The dovetailed jointing to some extent limits the body movements in the vertical plane but does not interfere with the extensive lateral play which is typical of a snake in movement. Illustrations by early naturalists and modern cartoonists often depict the progress of snakes and 'sea-serpents' in vertical undulations. This is entirely foreign to snakes, and to reptiles in general; such movement is, in fact, quite impossible because of the way the backbone is constructed.

The numerous, curved ribs which are joined in pairs to the trunk vertebrae are capable of certain movements. Lateral movement is seen under certain circumstances, as when flattening the body in the sunning attitude or when allowing passage of a meal which can be detected as a bulge along the body. No breast bone exists in snakes to hamper their movements. The movement of the ribs backwards and forwards, was at one time thought to play an important part in locomotion, but this has recently been criticised. Locomotion is now thought to operate under muscle action which is visible to the eye in the movement of the body surface, especially on the lower side.

In climbing or creeping at a slow pace some snakes are capable of moving forward in a perfectly straight line. A wave action on the lower sides of the body, which moves forward in a series of steps, is caused by successive contractions and relaxations of the muscles underneath. Attached to the ribs these muscles operate on the lower body surface which in most snakes is covered by a series of broad, transverse scales, known as *shields*. These shields correspond in number to the vertebrae and overlap, like roofing slates, along their hind edges. The free borders of the shields grip on to any rough surface or irregularity over which the snake happens to be passing, and this action is most apparent along those parts of the body which are in contact with the ground, rock or branch. This *rectilinear movement* has been compared with that of an earthworm, and has often been described as "a snake walking on its ribs". Actually, one gets a better analogy when one visualises the rowing of a boat. The oar-blade which grips the water corresponds to the ventral shield, the oar is the lever of rib and muscle and the ground is the fulcrum. Such movement is in common use in ground snakes, like our native adder, and arboreal snakes like the Aesculapian snake (*Elaphe longissima*) of South Europe (Fig. 1). This latter, like many of its relatives, has overlapping belly shields which bend at a sharp angle along their shorter sides. This forms a sharp keel which gives an extra grip on the smallest irregularities on bark or rock over which it climbs.





FIGS. 3 & 4.—Side and under view of skull of an Anaconda. (*Photos by Lionel Day, F.R.P.S.*)

The feats of climbing displayed by a pet Aesculapian snake in my collection reveal the high degree of specialisation achieved by snakes. This specimen will climb over the furniture or crawl along the picture-rail in my study, never missing its hold or making a false move. It can cling by its tail or any part of the body to the buttons of one's waistcoat, or hang from a projecting pen fixed into a pocket. When seeking a new perch it will stretch out its slender body in a horizontal plane to a third of its length, unsupported in the air, as it reaches over a gap to secure a fresh hold. The rest of the body, and in particular the prehensile tail, meanwhile retains a secure grip which it refuses to relax until the next foothold is secured. If I attempt to pull it free the grip is tightened. If I stand nearby it may attempt to bridge the gap in order to reach an arm or shoulder. Should I move slightly it draws back, remaining on its former perch. This is strongly reminiscent of an experienced mountaineer who always makes sure of his next step before he releases a previous foothold.

Along a tightened rope this snake will hang its body in loops over each side, edging itself along slowly in a remarkable display of co-ordinated muscle action in order to maintain its balance. Its 'star turn' is the grip it can maintain when hanging on to an electric light switch set into a wall. Here, on the only projection, less than half an inch, on a flat, vertical surface of many square feet, it will remain for over an hour never relaxing its grip.

A similar grip is used by this pet snake in constricting prey, a habit best known among boas and pythons. (It is indeed possible for a large boa or python to constrict and even kill a man, but there is no cause for alarm when a tamed python is coiled around one's neck or arm and commences to exert pressure; it is merely securing a firmer hold in order to prevent a fall.)

Rectilinear movement takes place at leisurely speed. At moderate or high speed a snake displays the typical *serpentine movement*, as it is called, where the body undulates in lateral curves and can thereby brace itself against projecting obstacles in its path. Without such projections a snake cannot proceed, as may be shown by placing it on a highly polished surface.

Where the flow of curves is restricted, as in a narrow tunnel, a snake may resort to yet a third locomotion called the *concertina movement*. At intervals along its body are stationary curves which press firmly against the sides of the tunnel, acting as anchors towards which and away from which the parts in between can be moved. In this way it progresses in steps along the tunnel (Fig. 8). Frequently a mixture of both this and rectilineal movement take place in which the belly shields at the stationary points along the body grip the underlying surface.

In some snakes, especially certain vipers and rattlesnakes, a curious sideways progression occurs. One North American rattlesnake (*Crotalus cerastes*), in fact, is named after this peculiarity. It is called the 'side-winder'. When side-winding a snake proceeds in a direction which is at an angle to that in which it is facing. The body does not follow the course of the head but, as it were, tacks away from a base line.

In burrowing snakes, of which *Typhlops* is a typical example, there are no broad belly shields, and the body is uniformly covered with polished and closely united scales of more or less equal size. This is also found in the slow-worm, a legless lizard which is fond of burrowing. There is no risk of earth particles becoming caught up in the skin, and the scales play no part in locomotion. Instead, the body twists and turns in all directions, pushing its curves against resisting bodies, such as stones, plants and the walls of burrows to propel itself forward. In some burrowing snakes (e.g. *Uropeltis*), the short tail ends abruptly in a broadened oblique surface, which is covered with large scales, and this operates somewhat like a digging implement.

The highly poisonous sea-snakes (which constitute the family Hydrophiinae)—these are the only 'sea-serpents' at present recognised by science—are entirely divorced from

the land, being viviparous and adapted for swimming. They have strongly compressed bodies and oar-like tails which present a broad surface to the water as they progress with lateral undulations. This compares with the movement of fishes, and is thought to be a relic of their fish ancestry. Even a land snake, such as the grass-snake, will swim in this manner over a pond—and for that matter 'swim' through the grass.

Yet another remarkable feat of some serpents is to be seen in the action of a 'flying' snake. This is much more in the nature of a glide but is nonetheless extraordinary. The ventral surface can be pulled in to form a deep concavity, accompanied by a slight flattening of the body, the kind of flattening which one would find if the body were squashed by a pressure applied above and below. The hollow under-surface gives the snake the necessary buoyancy in the air for its parachute-like descent into a lower branch, in a glide of some considerable distance.

In general, snakes which are well able to take care of themselves, such as the poisonous kinds and the large constrictors, are by nature sluggish, and many have squat clumsy bodies. They may even possess peculiar mechanical devices which are used to warn away enemies. There is, for instance the 'hood' of certain cobras produced by the flattening of the ribs behind the head when the animal is annoyed. Then there is the warning 'rattle' of the American Pit-viper, or rattlesnake; the rattle is composed of a series of rounded, horny sheaths at the end of the tail which is added to with each successive moult of the skin, and vibrates at high speed to produce a whirring sound intimidating to its enemies.

Defenceless snakes, burrowers and tree-climbers, on the other hand, are usually slender and built for speed. The record is probably held by the American Black Racer (*Coluber constrictor*), which is said to attain the speed of a running man.

The fastest of all snake movements, however, may be claimed by the vipers. Otherwise sluggish, and apt to stand their ground when attacked, they strike at lightning speed. When time permits, the rattlesnake or viper will coil the forequarters into the shape of a watch-spring with the head in the centre. This can then be shot forwards for about a third, even a half, the length of the body to produce one of the fastest movements in the reptile world. Only few animals, such as the mongoose and some birds, are able to avoid it, and even these are not always quick enough to avoid the strike (Fig. 2).

This brings us to another part of the snake's unique machinery, the jaws. In birds and mammals, ourselves included, there is only one articulation of the skull-bones, the point at which the lower jaw hinges on to the cranium. In a snake's skull the bones of the jaws function as prehensile organs, and do not masticate the food. They are attached to one another and to the cranium by elastic ligamentous tissue which permits for much distortion and wide expansion of the mouth. This, together with the expansion of ribs and body wall, allows for the passage of a prey which far exceeds in cross-section the size of the head.

The focal point of the jaw-action is at the point where, at the back of the skull, the two bones called the quadrate and pterygoid meet the lower jaw (see Figs. 3 & 4). As the quadrate bone is levered forward by muscle action a thrust

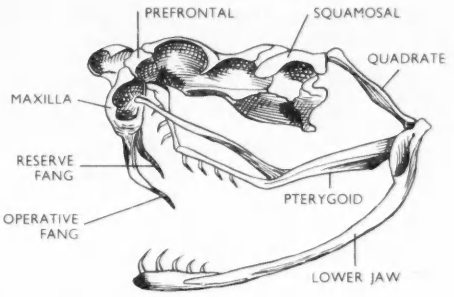


FIG. 5.—Skull of rattlesnake to show the mechanism of the jaw-bones in operating the poison fangs.

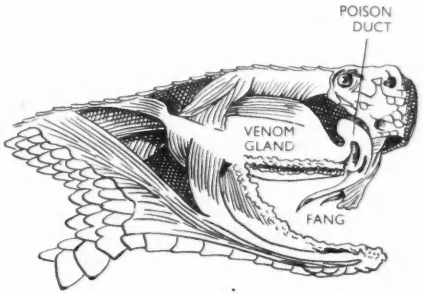
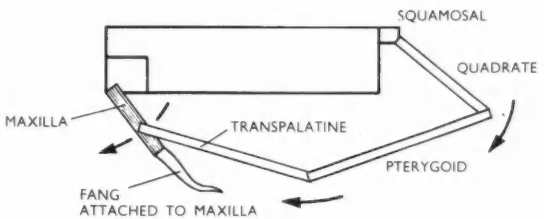


FIG. 6.—Sketch of partly dissected head of rattlesnake to show the poison apparatus. (*After Boulenger*)



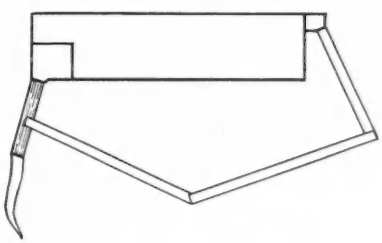


FIG. 7.—Erection of fang caused by rotation of the maxilla and the chain of bones connected to it.

is transmitted to both the upper and lower series of jawbones which possess teeth. These slide over the meal, hooking on further forward as the prey is worked down the gullet. The most noticeable movement is in the lower jaw, the two halves of which can separate widely at the tips, where normally they are held in place by elastic ligament. This allows for enormous expansion of a mouth with normally wide gape which extends to well beyond the eyes.

Each half of the jaw has independent movement, and is pushed forward alternately to its neighbour in a chewing action as the owner literally pulls itself over its prey. A copious flow of saliva in the mouth helps to lubricate the passage of the prey along the gullet. It is a slow and laborious process, painful to watch. Once past the teeth, swallowing is speeded up as the muscles in the body-wall take over, and the meal travels as a visible bulge into the stomach. Prey of large size is usually swallowed head first. By the mechanised means described above, which is peculiar to snakes, a python can swallow a fair-sized deer and a grass-snake can engulf a frog which is twice the diameter of its own head (Fig. 9).

The egg-eating snake (*Dasypeltis*) is capable of tackling a hen's egg, which is eaten whole. Certain of its vertebrae have enamelled tips projecting into the gullet. These crush the egg in its passage towards the stomach. The contents are swallowed and the egg-shell regurgitated as a pellet.

A typical snake's tooth in its layer of enamel is recurved and sharply pointed. It is used only for gripping food. Having no socket an ordinary tooth is easily broken off but soon replaced; reserve teeth grow from the gums lining the inner side of the jaw and move into position after each accident.

In some serpents certain teeth are modified into poison fangs. These are larger than the normal teeth, but retain the general pattern of prehensile teeth. They are used, however, for injecting the poison which is produced in one or other of the modified salivary glands. As with normal teeth they easily break off, and one method of defanging a snake is to allow it to strike at a cloth, which is then jerked away from the closed mouth. But again, a reserve tooth can grow into position and replace a fang that has been lost.

In the venomous snakes of the large family Colubridae, in which the long maxillary bone is fixed, the fangs may lie at the rear end of this, hence the name of their division, the Opisthoglypha. The fangs are usually too far back in the mouth and the poison too weak to make these snakes a real danger to man. The Montpellier Snake (*Malpolon monspessulanus*) is of this kind. A specimen which once bit me on the bare arm caused no further discomfort than the pain of the lacerated skin. On the other hand one of similar length, about 2 ft., bit and killed a grass-snake in my reptiliary.

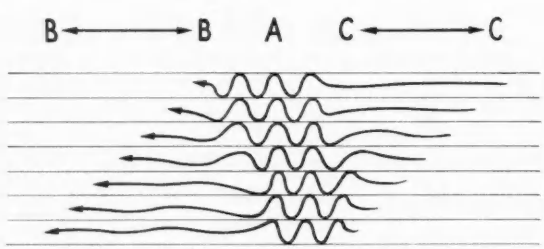


FIG. 8. Stages, from bottom to top, of concertina movement in a snake moving along a tunnel. A, Body at rest where it touches the tunnel walls. B, Body in front moving forward. C, Body behind being drawn up.

It is among their cousins, the division *Proteroglypha* or front-fanged snakes, that we meet the killers. Such are the cobras, kraits and mambas. Many of them bite with a bull-dog tenacity; they tend to hang on and force their fangs into the flesh with a chewing action. The result is often a severe laceration, and this may be accompanied by much loss of poison as it leaks out of the wound. Both groups, front-fanged or back-fanged, have permanently erect fangs in the fixed maxillary bones.

The whole operation is in many cases a clumsy affair and not always as swift as one imagines. A rearing cobra may look a fearsome sight, yet some people will approach and tease it with impunity.

Far more efficient and less wasteful is the poison mechanism of the family Viperidae, which include the Old World vipers and the New World rattlesnakes. Here the maxillary bones are short and so placed that they can rotate on their front axes where they join the prefrontal bones of the cranium (see Fig. 5). At rest the maxillaries are so placed that the fangs, which are firmly fixed to them, point backwards and lie along the roof of the mouth. Protected in this way when not in use, they may grow to considerable length, sometimes not far short of 3 in., as in the Gabun Viper of Africa.

With the mouth open the viper or rattlesnake brings into operation a set of muscles which puts the highly mobile jawbones through a series of lever actions, in such a way that the short maxillary bones are rotated through an angle of about 90°. This brings the fangs into position for the lightning thrust which follows (Fig. 7).

The erection of a viper's fangs is an independent action, not necessarily used only during striking. I have watched an adder yawn to ease its facial muscles, slowly raising each fang in turn, where no attempt was made to strike. It once took and swallowed a lizard alive, in which act the fangs remained in the resting position.

The groove along the front edge of the fang, as seen in cobras, is completed into an internal canal in the Viperidae. In such a canalised tooth there is an inner opening which appears as a slit at the base of the fang on the posterior side. This communicates with a duct leading to the poison sac, which in the viper is a modified salivary gland lying in the roof of the mouth just below the eye. The outer opening of the fang is set just behind the tip, whose needle sharpness is thereby not impaired. Venom is stored in the spaces within the sac, upon which pressure is brought to bear by the flexion of the facial muscles. These are in close relation with the venom sac, which is squeezed by the muscles in a kind of wringing action. Venom passes via the duct which lies over the maxillary bone, into the hollow fang which is protected by a thick, mucous sheath, and so into the wound. Not a single drop need be wasted (Fig. 6).

In some cases poison is actually thrown from the fang some distance from its target. In some of the 'spitting cobras' the poison may be ejected with considerable accuracy to a distance of up to eight feet. Whether the aim is deliberate is not fully understood. Boulenger makes the suggestion that the poison is mixed with the snake's normal saliva and squirted through an opening in the membranes

lining the mouth which act as lips. If so, then this action would entitle this cobra to its popular name.

Nature's Hypodermic

A snake's fang is a mechanical masterpiece and nature's parallel to the hypodermic needle. Like the surgical instrument it is only used when necessary, for most snakes strike only as a means of defence or to kill prey. Hair-raising stories of vicious serpents which pursue and leap at their victims, in other words make a deliberate onslaught, are usually figments of the imagination. Deliberate attack as opposed to defence is a rare thing.

The above remarks will make it appear that the life of the lowly serpent is a matter for compensation, for "what it loses on the roundabouts it gains on the swings". It cannot masticate its food so it swallows it whole; in this it can put a healthy human appetite to shame, yet it can, if forced to, starve for over a year. Limbs as such are missing, so it 'walks' on its ribs, swims and grips with its tail and climbs on its scales. The outer skin does not grow, so from time to time is peeled off neatly, even to the scales over the eyes. Taste is poor, but this is compensated for by a strong sense of smell, in which the harmless tongue assists by catching the smell particles from the air. In hearing it is proverbially deaf, but may receive ample warning of danger from vibrations through solid objects, which reach its sensitive skin more swiftly than sound can travel through air. Prey it can tackle and kill with a choice of two methods, poisoning or constriction, or it can merely swallow it alive.

The customs official, indeed many of us, may well puzzle over this 'limbless quadruped' of the herpetologist, but would no doubt agree with all the fame and notoriety which it enjoys. It holds a position unique among animals in being able to attract yet at the same time repel the observer. Symbol of healing or of evil, feared in one place and worshipped in another, it is steeped in legend and folklore.

Enemy of man and persecuted unmercifully the serpent may yet hold its own in a hostile world for many years to come, owing its survival to the unique machinery of its skeleton with which, as Sir Richard Owen once said, "It can out-climb the monkey, out-swim the fish, out-leap the jerboa and out-wrestle the athlete."

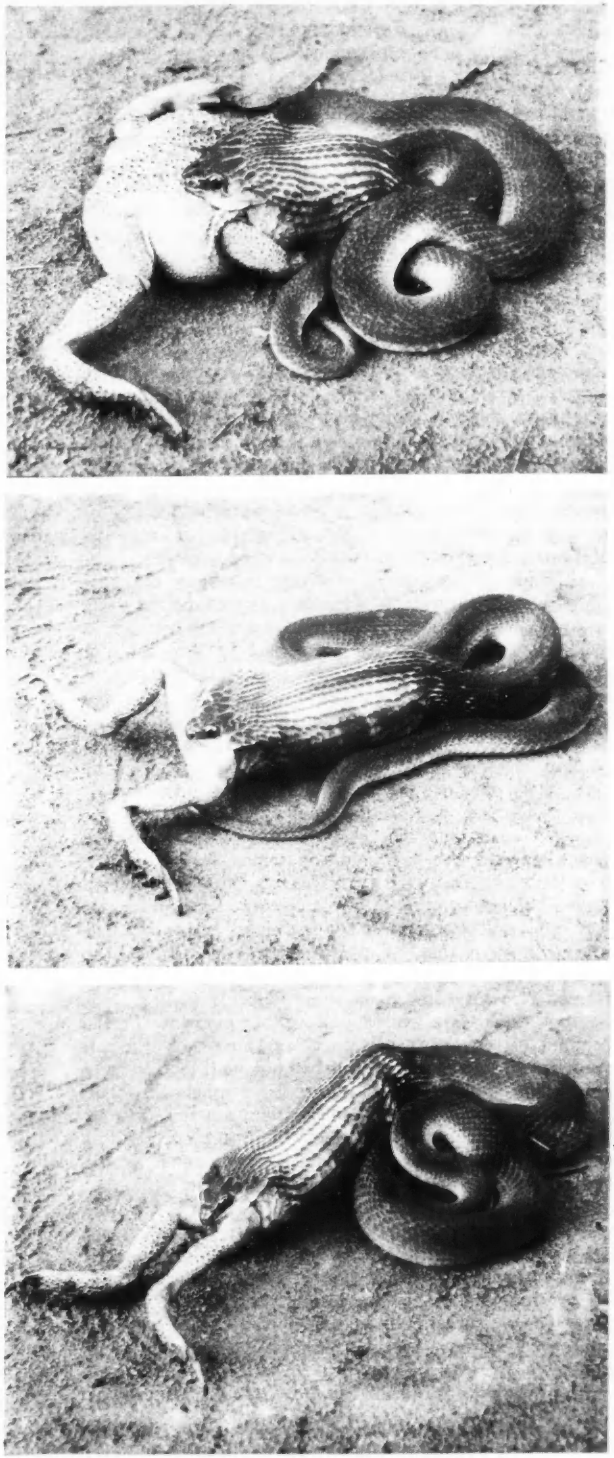


FIG. 9.—These pictures show a toad in process of being swallowed by a Green Grass Snake (otherwise known as the Green Keelback, *Macropisthodon plumbicolor*). The snake alternately advances the right and left sides of its upper jaw, obtains a purchase with its teeth and draws the toad into itself or rather slips itself over the toad. The swallowing occupies about one hour, and digestion has probably begun on the head before the hind legs disappear. (*Photos by O. C. Edwards, A.R.P.S.*)

Chromatography in Industry

TREVOR I. WILLIAMS, B.Sc., D.Phil.

THE history of chromatography has been unusual in many ways. Discovered and quite widely applied in several different fields in the opening years of this century, its full possibilities as a tool for chemical research were not realised until some thirty years later, but from then onwards it was exploited and developed with almost bewildering speed.* Mixtures of almost every kind—coloured and colourless, organic and inorganic—proved readily separable by chromatographic means. Two completely new types of chromatography have been developed in the past decade; partition chromatography, a most versatile and elegant method of analysis which in its most sensitive form is carried out on sheets of paper, and chromatography on columns of ion-exchange materials similar to those used in domestic water-softening plants. Despite these remarkable achievements, however, which compel recognition of chromatography as one of the most important single developments in chemical technique of this century, the possibilities of chromatography as an industrial process are only now beginning to be explored.

Although the principles of chromatography are now fairly generally known, it is perhaps as well, before going on to consider the industrial possibilities of the method, to recall its essential features. Suppose, for the sake of example, that a solution in petrol of the natural pigments of leaves is allowed to percolate through a vertical glass tube packed with finely divided calcium carbonate. At first, as is to be expected, the calcium carbonate at the top of the column becomes stained a dark greenish-yellow. This is because the powder adsorbs the pigments on the surface of its particles. As more solution passes through the column, however, a striking difference is seen. First of all the powder is seen to be wet, but not stained, far beyond the discoloured region at the top. This is because the top part of the column has completely adsorbed the pigment, so that only almost colourless solvent passes on down. The other change is that, as careful examination shows, the coloured region is no longer quite uniform; bands have formed across it, some green, some yellow (Fig. 2). This is because the natural green and yellow pigments in the original mixture are adsorbed with varying ease by the calcium carbonate. Strongly adsorbed pigments tend to cling to the top of the column, and the less strongly adsorbed ones, as it were jostled out of position, are found lower down. If the column is washed with more solvent this separation becomes much more striking, so much so that completely colourless regions appear between the coloured zones. If the moist column is then pushed out of the tube containing it, the regions carrying the various different pigments can be separated with a knife. This pattern of coloured bands is called a chromatogram. Alternatively, by continuing the washing of the column the different zones can be successively washed out at the bottom and collected in different receivers forming a liquid chromatogram.

Many other adsorbents can be used besides calcium carbonate; for example, lime, starch, or powdered talc. By using special methods to locate them, colourless substances can now be subjected to chromatographic analysis almost as easily as coloured ones. As already mentioned, chromatography can also be carried out on columns packed not with adsorbents but with ion-exchange materials or with water-carrying substances like silica gel.

The industrial possibilities are most conveniently discussed in relation to adsorption chromatography, the method which is epitomised by the classic separation at different levels on a calcium carbonate column of the various leaf pigments. It must be remembered, however, that two other forms of chromatography—by partition and by ion-exchange—are now sufficiently firmly established to deserve equally close consideration.

Before discussing the particular merits of chromatography, it is very important to distinguish this from the other processes of adsorption which are traditional in the chemical industry. For example, the decolorisation of solutions by filtering them through beds of charcoal is well known and certain oils are bleached by passing through fuller's earth or other adsorbents; such a process is *not* truly chromatographic for it merely separates the material into two fractions, one the liquid which flows from the

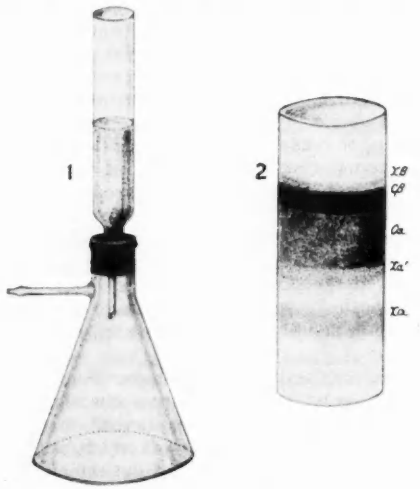


FIG. 1 (*left*).—Practically the first demonstration of the effectiveness of chromatographic analysis was the separation by the Russian botanist Twsett of the pigments present in plant leaves. This diagram shows his apparatus, consisting of a vertical glass tube plugged with cotton wool at its lower end and containing a column of powdered calcium carbonate.

FIG. 2 (*right*).—The chromatogram Twsett obtained by filtering his solution of leaf pigments through the column of calcium carbonate. The individual pigments have become arranged in successive bands; the letters indicate their position in the column according to the following key: $x\beta$ xanthophyll *b* (yellow); $c\beta$, chlorophyll *b* (olive green); $c\alpha$, chlorophyll *a* (bluish green); $x\alpha'$, xanthophyll a' and a'' (yellow); $x\alpha$, xanthophyll *a* (orange yellow).

* The principles of chromatography were described by Dr. Trevor Williams in a DISCOVERY article (April 1945, pp. 116–21).

bottom of the column and the other the substances retained on the adsorbent. Chromatography is far more selective, for under the appropriate conditions the substances retained on the adsorbent are spatially separated and thus can easily be isolated one from another.

The mere versatility of chromatography and its success in the laboratory does not, of course, alone justify faith in its possibilities as an industrial process, for commercial success demands also that the method shall be both simple and effective and that the cost shall be consistent with the results obtained.

The simplicity and effectiveness of chromatography is amply confirmed by a literature, comprising many thousands of references, extending over half a century. Consideration of the various economic factors and comparison with the costs of other large-scale adsorption processes already long-established in industry strongly suggest that chromatography can also be a paying proposition. The apparatus required need not be very elaborate when judged by normal chemical engineering standards. It must, speaking generally, consist of a container for the adsorbent, with a means of filling and discharging it, and a means of isolating the different zones of the chromatogram that is formed. Most of these problems are common to all industrial processes of adsorption and can be considered as satisfactorily solved so far as general principles are concerned.

The nature of the solvent used in chromatography is of decisive importance for effecting a satisfactory separation, and the choice of solvent for any particular process may, therefore, be limited. In some cases satisfactory results can be obtained only with expensive solvents such as chloroform; the outlay on solvent may be considerable, but it can, however, be regarded as essentially a capital expense, for with a properly designed plant very little solvent should be lost in each cycle of operation. The same argument may be applied to the adsorbent material; alumina and modern synthetic ion-exchange materials are relatively expensive, but if the solutions put through them are properly prepared it should be possible to regenerate the materials almost indefinitely. (Some water-softening plants, for example, which have been in constant use for many years, still contain the original charge of softening material.) In many cases, however, it can be expected that industrial chromatography might be carried out with both cheap solvents (even water), and cheap adsorbents, such as lime or fuller's earth. As a general rule inorganic chromatography, which during the last few years has developed very rapidly indeed, must generally be carried out in aqueous solution because the substances to be separated will dissolve only in water.

The economic possibilities of many processes depend upon the speed with which they can be carried out and this applies particularly to chromatography. The normal rate of flow of a solution through a large column of finely powdered material is naturally very slow, particularly if a rather viscous solvent is used, and although excellent separations may be effected under such conditions, the small yield may rule out commercial success. It is, however, normally possible to accelerate the rate of flow considerably, preferably by applying pressure to the top of the column; this can be done without seriously affecting the sharpness of the chromatogram. This same factor of speed is encountered in all industrial adsorption processes and one solution commonly adopted has been to arrange the adsorbent not as a column but in the form of a hollow cylinder, the liquid to be filtered flowing through the walls of the cylinder. In this way a relatively large surface area is obtained and the rate of flow is therefore much increased. In a recent British patent the same idea has been applied to industrial chromatography. According to this proposal the adsorbent is arranged in the form of a thin disc, through the centre of which runs a vertical channel. The mixture to be split up moves in solution outwards from this channel to the outer walls of the disc and the zones of the chromatogram in this case naturally form a series of concentric cylinders. These cylindrical zones may be separated in two ways. One method proposed is to have a system of rotating knives which scoop out the cylinder of adsorbent containing a particular substance. The other is to form what has already been referred to as a liquid chromatogram, that is to say the adsorbent is continuously washed with a suitable solvent until the zones of the chromatogram successively wash out in solution through the outer wall of the adsorbent. By changing the receiver as each new zone washes through, the different substances can be separated from each other. This device has been called a chromatofuge because one method proposed for accelerating the rate of flow is to rotate the cylinder rapidly so that the liquid is forced through by centrifugal force. In general, however, the most satisfactory method of accelerating the flow is by applying pressure to the liquid. So far, separations with the chromatofuge have been limited to experiments with a small model, but these seem to have been satisfactory. For example, castor oil is reported to have been freed from ricinoleic acid and other impurities at the rate of seventy gallons an hour. In another experiment five gallons of oleic acid was separated from twelve gallons of ricinoleic acid on finely powdered barium carbonate.

The choice of experiments for the model of the chromatofuge is significant, for the possibilities of chromatography in the fat and oil industry seem particularly bright and there is already an extensive literature and several patents have been filed, including some taken out in Germany during the war. Published reports indicate, for example, that chromatography could not only convert crude fish oil into a useful drying oil but could at the same time recover many useful by-products.

One of the most interesting industrial applications of chromatography made up to the present is one sponsored by Valley Vitamins Inc., at their factory in Texas. (Fig. 3.) Its object was to separate the natural leaf pigments chlorophyll, β-carotene, and xanthophyll present in dried lucerne. This is done by pumping the crude solution of pigments, which results from the treatment of the lucerne leaves with hexane, upwards through columns of carbon black. The columns are arranged in batteries of six; each column is about 12 ft. high and 3 ft. in diameter. At first almost pure hexane flows out of the top of the columns. After a time a yellow solution of carotene appears. At this stage the supply of crude leaf-pigment solution to the columns is discontinued; instead pure hexane is passed up the columns. The yellow carotene solution that flows out of the columns is collected, and from it a solution of practically pure β-carotene is obtained by further chromatographic treatment.

When the carotene has all passed through the columns

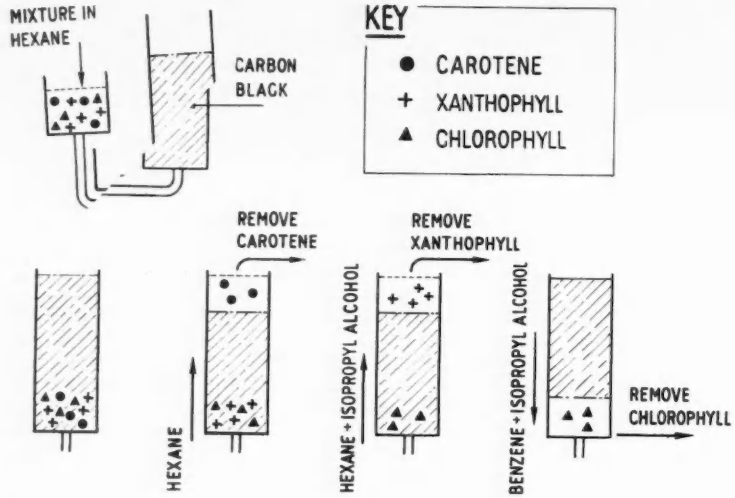


FIG. 3.—The scheme for the separation of leaf pigments on a commercial scale.

the flow of hexane up the column is interrupted, and it is replaced by a mixture of hexane and isopropyl alcohol. This washes the xanthophyll through; all of it can be collected within the space of about four hours.

Once again the solvent is changed, this time to a mixture of benzene and isopropyl alcohol, and the direction of flow is also altered, being now from the top of the column to the bottom. This treatment causes chlorophyll to wash out in solution from the bottom of the column, the whole process being complete in about eight hours. The reversal of flow is necessary because even after the carotene and xanthophyll have been removed, the chlorophyll is still much nearer the bottom of the columns than the top owing to its strong adsorption.

This process very simply separates the three main pigments in the original mixture—a result not easily achieved in any other way—and at the end of the process the columns of carbon black are left completely regenerated and ready for a fresh cycle of operations.

Chromatography has played an important part in the industrial production of streptomycin, for Merck and Co., at their factory in Virginia, successfully introduced the method for the purification of the crude drug. The separation was carried out in methyl alcohol solution on columns of alumina.

It is interesting to note that these two examples of industrial chromatography, admirably illustrate two distinct uses of the method. In the Valley Vitamins process the method is used to separate substances which are present to roughly the same extent in a mixture which contains comparatively little in the way of other impurities. In the Merck process, however, conditions were quite different. Here the desired substance, streptomycin, was a comparatively minor constituent of the original mixture and many other impurities were present. The success of chromatography under these two different conditions affords further evidence of its versatility.

A further industrial application of chromatography is being made by British Drug Houses, which is using the method with success for the preparation of amino-acids.

In conclusion it may be remarked that the now vast literature relating to chromatography contains many examples of the use of very large columns, even though these were not designed for continuous industrial use. For example, in the United States columns up to 50 ft. in length have been used to separate mixtures of hydrocarbons. The original separation of Vitamin K from lucerne was carried out solely by the use of chromatographic processes, some involving columns containing as much as four hundredweight of adsorbent. In the Plutonium Project, during the war, batteries of chromatographic columns, each column 9 ft. long, were used to separate mixtures of rare earths and other inorganic substances.

Summarising the present position, it may be said that the very extensive technical literature relating directly to the industrial exploitation of chromatography and the great additional number of published papers which are indirectly relevant to this problem may be taken as an indication that rapid developments are to be expected in this field even though the existing applications are relatively few. It can be predicted with considerable confidence that once industrial applications begin seriously, progress will come surprisingly rapidly. It may well be that in the not far distant future chromatography may be as commonplace in industry as distillation and crystallisation are today.

READING LIST

Standard books on chromatography include the following:

Chromatographic Adsorption Analysis, by H. Strain (Interscience Publishers, New York, 1942).

An Introduction to Chromatography, by Trevor I. Williams (Blackie & Son, London and Glasgow, 1946).

Progress in Chromatography (1938–47), by L. Zechmeister (Chapman & Hall, London, 1950).

Among the more important papers on industrial applications of chromatography are the following:

C. G. Lynam and H. Weil, "A New Plant for Radial Chromatography", *Manufacturing Chemist* (1950), **21**, 195.

H. Weil, "Industrial Oil and Fat Chromatography", *Paint Technology* (1949), **14**, 391, 439.

T. I. Williams, "Chromatography in Industry", *Industrial Chemist* (1948), p. 316.

R. Williams, Jr., and J. V. Hightower, "Chromatography", *Chemical Engineering*, Nov. 1948, **55**, 133.

Robert Boyle: Founder of Experimental Physics

C. L. BOLTZ

To call Robert Boyle the founder of experimental physics may seem a large claim, and it is. It is justified, as far as any claim for one man alone is justified, for it was Boyle who insisted, in precept *and* practice, on careful and continued experimentation. The foundation of the modern method in science has been attributed to Francis Bacon, and he certainly said a great deal of importance about it; but he did not perform experiments. It has also been attributed to great Galileo—original investigator, deft manipulator, outspoken partisan—yet in elementary physics he was not always reliable, as will be shown below.

There are others as well in the seventeenth century, such as Pascal and Mersenne and Descartes, who contributed to the revolution in science that tended towards experimental evidence but who were still sufficiently imbued with past learning to relish a pretty theory without always seeing the need for experiment. Even the experiments they did perform were not always regarded seriously as evidence, but were, so to speak, thrown off carelessly as byplay. Indeed some of the 'experiments' they described were not capable of performance. Pascal, for instance, whose laws of fluid behaviour are part of today's elements of physics, described several such 'experiments'. Boyle with extraordinary restraint merely observed: "whether or no Monsieur Pascal ever made the experiments himself; he does not seem to have been very desirous that others should make them after him. For he supposes the phenomena he builds upon to be produced fifteen or twenty foot under water. And one of them requires that a man should sit there with the end of a tube leaning upon his thigh. But he neither teaches us how a man shall be enabled to continue under water, nor how in a great cistern full of water, twenty-foot deep, the experimenter should be able to discern the alterations, that happen to mercury and other bodies at the bottom." The gallant gentlemen listening to Boyle saying this at the Royal Society must have been considerably entertained.

Boyle's own attitude was quite different. For him it was experiment first and always, experiment done with every possible care. He aimed as he put it to write 'history', that is, descriptions of experiments to build up a mass of data for future scientists to use as a basis for discussion and theorising. It would be going too far to say he first introduced precision in the modern sense into observation, for he knew the limitations and gave many of his results as only approximate; but he was insistent on care and 'wariness'. There is an excellent example of the differences in procedure between Boyle and others in the determination of the weight of the air in relation to the weight of an equal volume of water. (Boyle invented the term *specific gravity* for this ratio, and it has been used ever since, being replaced by *relative density* only very recently.)

Whether the air had weight or not was still a live issue half-way through the seventeenth century. Galileo had shown that, contrary to Aristotelian dogma, air had weight. To find its specific gravity he used a flask that he could connect *via* a valve to a second flask. He compressed air into the first with a syringe and weighed it. He filled the second flask with water and connected it to the first and opened the valve. The compressed air escaped into the second vessel and drove the water out. This water was weighed. Then the first flask was weighed again. Clearly, said Galileo, the volume of water displaced was equal to the volume of air released. So all that had to be done was to divide the weight of displaced water by the loss in weight of the first flask after expulsion of the compressed air. The answer was, he said, 400. In modern terms, the specific gravity of air was 0·0025. He quoted no figures, only the final result. It is evident that his answer was not an important figure to him except in so far as it proved Aristotle wrong.

Descartes used a different method. He took a glass bulb the size of a tennis ball with a tapering neck having an opening of only a 'hair's breadth'. He weighed this cold. Then he heated it and weighed it again while still hot. He then plunged the orifice under water and allowed the bulb to cool. Water was thus drawn in. He then weighed again. The increase in weight gave him the weight of water. The loss in weight in the first two weighings gave him the weight of air. According to him the relative density of air was 0·0067. He admitted that he might be in error and suggested to Mersenne that he might like to repeat the experiment. This Mersenne did, using a copper bulb instead of a glass one (also with, so he said, an orifice of one hair's breadth). He used a similar procedure but was able to get his bulb much hotter than Descartes' glass one. His result for the relative density was 0·0007.

Boyle also used a metal bulb with a long neck and narrow orifice. He heated it as hot as he could without melting the solder and then sealed the opening. This partially-exhausted bulb was then weighed cold. He pierced the seal, the air whistled in, and he weighed again. In this way he found the weight of cold air that the bulb would hold if it could be assumed that he had driven all of it out by heating. Then he filled it with water and weighed it when cold, thus getting the weight of water equal in volume to the air whose weight he had already found. His result for the relative density of air was 0·0011.

There is no need to examine the several methods to find the errors involved and the assumptions made. All that is necessary is to tabulate the results and compare them with the accepted value for today, taken at 0 C. and 760 millimetres of mercury pressure.

SPECIFIC GRAVITY OF AIR

Date	*Experimenter*	*Result*	*Today's value*
*c.*1600	Galileo	0·0025	
*c.*1642	Descartes	0·0067	
*c.*1642	Mersenne	0·0007	0·0013
*c.*1659	Boyle	0·0011	

The results speak for themselves. Yet Boyle made no claim to precision, for he realised vaguely that standard conditions were necessary. All he claimed was care in the

experiment. He said that for rough purposes the specific gravity of air could be taken as 0·001. So it could; and so it can today.

The man who obtained this result—only one of many that were to come from him—is known to us today merely by his surname. He was in fact the Honourable Robert Boyle, seventh son and fourteenth child of that historical figure, the brave and ambitious coloniser-adventurer, the 'great' Earl of Cork. Most of the Earl's daughters married dissolute sprigs of the nobility, and many of his sons were wild and extravagant. In contrast, Robert (born in 1627) was quiet, obedient, studious, and he was always the old man's pet. At Eton he was given preferential treatment by his housemaster and yet he never became a prig. He was a stammerer and physically weak, and when he grew to manhood he was tall, lean, and emaciated. In the midst of the Civil War he returned from a post-Etonian continental tour to find himself the owner of estates in England and Ireland. He was a sensitive, pious man, and he wrote extensively on religious matters.

He was very excited by the mathematics to which he was introduced by his tutor in Geneva, and in the London of the Civil War he met the leading intellectuals, members of the "Invisible College" as he called them, who appreciated the young man's integrity and intelligence. In this company, which he enjoyed immensely, he absorbed advanced anti-Scholastic views and learned of the atomistic conception of matter, then being revived. He made himself a laboratory at his estate in Dorsetshire and in 1654 left the country for Oxford to rejoin the Invisible College. Here he remained fourteen years. He had a laboratory organised and employed a number of assistants, one of whom was Robert Hooke. Hooke had been entered at Oxford as a 'servitor', which means that he had board and lodging and tuition free, for which he waited on the Fellows of his college. It was therefore natural for him to be an employed person at first until his genius was recognised. This accounts for the early anonymity of his work and has led some critics into the extreme view of attributing to Hooke achievements due to Boyle, an attitude just as wrong as the early opposite one.

Boyle's integrity and charm were such that there was never a breath of scandal about him in a period notorious for dissolute living, and he never had an enemy (not even Hooke). At his zenith he was acknowledged the most learned man of his time and people from all over Europe came to visit him when he lived in London after leaving Oxford. He was offered a peerage by Charles II and refused. He also refused the presidency of the Royal Society, of which he was a foundation member from its inception in 1660. He remained a bachelor until his death—in 1691. In fact his life was a dedication to one thing, the pursuit of truth according to his lights.

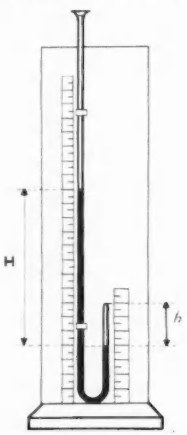


FIG. 1.—Apparatus as often used today in schools for demonstrating Boyle's Law. Mercury poured into the open top of the tube increases the pressure on the air enclosed in the short limb. The volume of that air is inversely proportional to the pressure to which it is subjected.

Robert Boyle was also, though it has rarely been said, a populariser of science. His writing was clear, though it is too wordy for modern taste, but it has to be remembered that he was writing in the seventeenth century, a leisurely time when no conditional clause was ever omitted, no subjunctive evaded, and when every *t* had to be crossed and every *i* dotted. If this fact is allowed for, his writing is clear, to the point, and absolutely devoid of dogma. His first book established his reputation all over the civilised world and another of his scientific books ran into several editions during his lifetime. In many of these books he used a systematic treatment by numbering his sections and devoting each one to a single experiment. Another device was the investigation of 'paradoxes', a paradox being a statement in direct opposition to that held by orthodox Scholastics. (In this sense the statement "Air has weight" would be a paradox.) Boyle's popularising extended to lecture and demonstration. He was in such demand among the people of high society, including the women, as well as among intellectuals, that in self-defence he eventually had to publish a time-table warning would-be visitors of the days and times when he would be "not at home".

In 1657, three years after he had settled in at Oxford, a book was published by the Jesuit scientist Kaspar Schott. In it appeared the first published record of experiments done by Otto ('magdeburg-hemispheres') von Guericke with a pump designed to remove air from a container. This was the first vacuum pump in history. Boyle was excited by the news and realised that there were plenty of experiments to be done in, and with, an evacuated receiver, experiments connected with the controversial subject of air and its weight. Von Guericke's pump, however, was a cumbersome affair; two men had to work continuously for several hours in order to evacuate the receiver. Moreover this vessel had only one orifice, that through which the air was abstracted, so it could not conveniently be used as a miniature laboratory. Accordingly Boyle asked his research assistants "Mr. G." (Probably Gregg his 'operator') and Robert Hooke to devise a more convenient pump and receiver, which the latter eventually did.

The pump is shown schematically in Fig. 2. The top glass vessel, 15 in. or so in diameter, is the receiver A, with a double opening (1) at the top, one large, one small. It is connected by a stopcock (2) to the vacuum pump B, which has a leather piston attached to an iron corrugated strip (D) projecting through the base of the cylinder. A toothed wheel meshes with the corrugations and is rotated by means of a handle (E). Opening No. 3 is ground to receive a brass stopper, also carefully ground.

The operator of this pump had to be something of an athlete, not to say acrobat. The procedure was to close 2, pull out 3, wind the piston to the top, push in 3, open 2, wind the piston to the bottom, and so on. This had to be nimbly done because there was such difficulty in getting

airtight joints with the lutes available (one plaster consisted of water, lime, and cheese-scrapings, the whole having a "strong and stinking smell") that many an experiment had to be done at the first stroke of the pump.

With this instrument, Boyle and his assistants did a number of experiments. Descriptions of these were added to those of other experiments related to the same subject but not necessarily involving the pump, making 43 experiments altogether, and published in 1660 under the title: *New Experiments Physico-Mechanicall Touching the Spring of the Air and its Effects*. With this book Boyle at the age of 33 became famous.

In the 43 experiments Boyle gave convincing evidence that air had weight and that atmospheric pressure would account more satisfactorily for phenomena attributed by Aristotelians to nature's "abhorrence of a vacuum". He also showed a connexion between combustion and respiration in that a candle quickly went out in a partial vacuum and a mouse fainted but revived when air was reintroduced. Moreover he showed that light and magnetism penetrated a vacuum whereas sound did not, the latter a direct refutation of orthodox belief. He invented the term *barometer* and measured the atmospheric pressure directly, making it come to 112 lb. over the area of the piston (3 in. in diameter). (In modern terms Boyle's result came to just under 16 lb. to the square inch.) He argued that what was usually called suction was really a matter of difference of air pressure. He found the relative density of air in the way already described. With regard to the atmosphere he suggested that there might be "strange ebbings and flowings, as it were, in the atmosphere; or at least, that it may admit great and sudden mutations, either as to its altitude or its density, from causes, as well unknown to us, as the effects are unheeded by us". He found the relative density of mercury by two methods, one of which has been the standard procedure ever since for finding the relative density of liquids—the method of the specific gravity bottle. His results were 13·76 and 13·68 (modern value 13·60 to 2 decimal places) and he took the value as being 14 for rough calculation. With this figure and the relative density of air as 0·001 he calculated the height of the atmosphere, making it come to about 7 miles, though he added a warning that this calculation depended on an unjustifiable assumption that the air was everywhere uniform. It might be, he said, more and more rarified upwards to a very great height. He noted also, when he used very fine tubes, peculiarities that he could not account for—the earliest mention of the phenomenon now called capillarity.

Only a few of the carefully ascertained facts and the ideas thrown out in passing have been mentioned. It is easy to understand the excitement caused at the time by this little book.

A second edition appeared in 1662. To this he added replies to criticisms made by Thomas Hobbes and Francis Line, a Jesuit teacher who refused to accept evidence of a vacuum. Boyle had already suggested an atomistic or corpuscularian explanation of the behaviour of air under compression or rarefaction. He considered air as composed of tiny particles that acted like springs, from which it followed that the more they were compressed the more they would press out against the compressing force. In other words, the smaller the volume became under compression, the greater was the pressure exerted by the air. He now

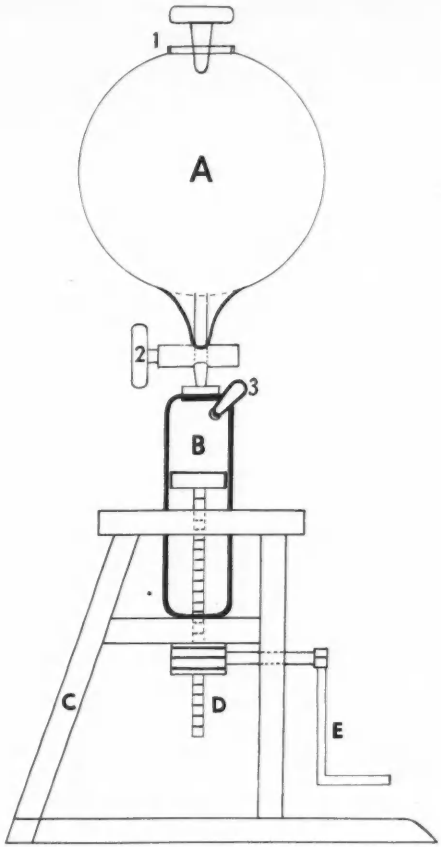


FIG. 2. Schematic simplified diagram of the pump and receiver.

subjected this hypothesis to test in a glass tube several feet long bent round at one end. The long limb was open and the short one closed. Mercury was poured into the tube, thus enclosing some air in the short limb. An assistant on a pair of steps poured mercury in at the top while Boyle noted carefully the heights in the short limb and the long one. He tabulated his results and multiplied the total pressure (exerted on the small amount of air) by the length of air column at the beginning of the experiment. This figure should have remained constant throughout the experiment if his hypothesis was correct, so he divided it by each new length of air column and thus obtained what the pressure should have been. The column of these results was shown side by side with the actual pressures he found. The agreement between the two columns would satisfy most present-day students but they did not quite satisfy Boyle. They were good enough, he contended, to show that his hypothesis that pressure and volume were in reciprocal proportion was a good one, but they were not good enough for an unequivocal statement of the law. This law, known ever since in the English-speaking world as Boyle's Law, is usually expressed today in the form:

$$pressure \times volume = constant.$$

We know now that Boyle's doubts were justified, for only an 'ideal gas' obeys Boyle's Law.

Much of his subsequent work was concerned with the branch we now call General Physics or The Properties of Matter. In 1666 he produced *Hydrostatical Paradoxes*, in which he described experiments that were, unlike Pascal's, actually performable. With these he established the laws of fluid pressure. In 1669 followed *A Continuation of New Experiments Physico-Mechanical*. In this he described the siphon barometer, calling it himself a 'portable' barometer. He also showed that the heights of liquids in wide tubes when the air above was removed were inversely proportional to their densities. He described a gauge for measuring the degree of evacuation. The pump used was one newly designed. In 1690 there appeared a book oddly called *Medicina Hydrostatica*. This was really a treatise on specific gravity and methods of finding it for liquids, solids, and powders. He described two sorts of hydrometer, one being a glass tube ballasted with mercury. But the chief thing about this book was that in it Boyle insisted on relative density as a very important property of any substance. This is perfectly true, as anyone can verify by glancing at a book of physical constants today. Boyle showed that this constant could be utilised in detecting adulteration, ascertaining the stages of fermentation, exposing false claims related to gems, and so on.

All the problems bothering his contemporary scientists were tackled. He wrote on heat and cold. Especially he produced a remarkable book on colour called *Experiments and Considerations touching Colours*. This appeared in 1664 and was so popular that some French people, we are told, actually learned English in order to read it rather than wait for the Latin version. Fifty numbered experiments were described. The book was remarkable for the fact that Boyle established the subjective nature of sensation and was only willing to take an objective view as a convenience. He argued also that colour was caused by the interference (in the normal sense, not as a technical term in optics) of the surface of a substance with the light that struck it. These contentions were opposed entirely to the views accepted by the orthodox Scholastics and by the alchemists and by the followers of Paracelsus. In the course of his descriptions Boyle placed on record for the first time some details of phenomena now known as after-image phenomena.

The mention of alchemists reminds us that Boyle was himself one. This seems a contradiction of his scientific realism. It had two drives. The first was connected with the desire of a man always ill for a panacea for human ailments. The second drive was perfectly logical. Boyle as an atomist believed that every substance was merely a rearrangement of the same basic units. So it was only necessary to find the way to rearrange these units to be able to transmute any substance into another, even into gold. People looking superciliously on this foible of Boyle's may remind themselves that this sort of transmutation is now being done daily in nuclear reactors at Harwell and elsewhere.

THE THUNDERSTORM: A NATURAL DYNAMO—*Continued from p. 389*

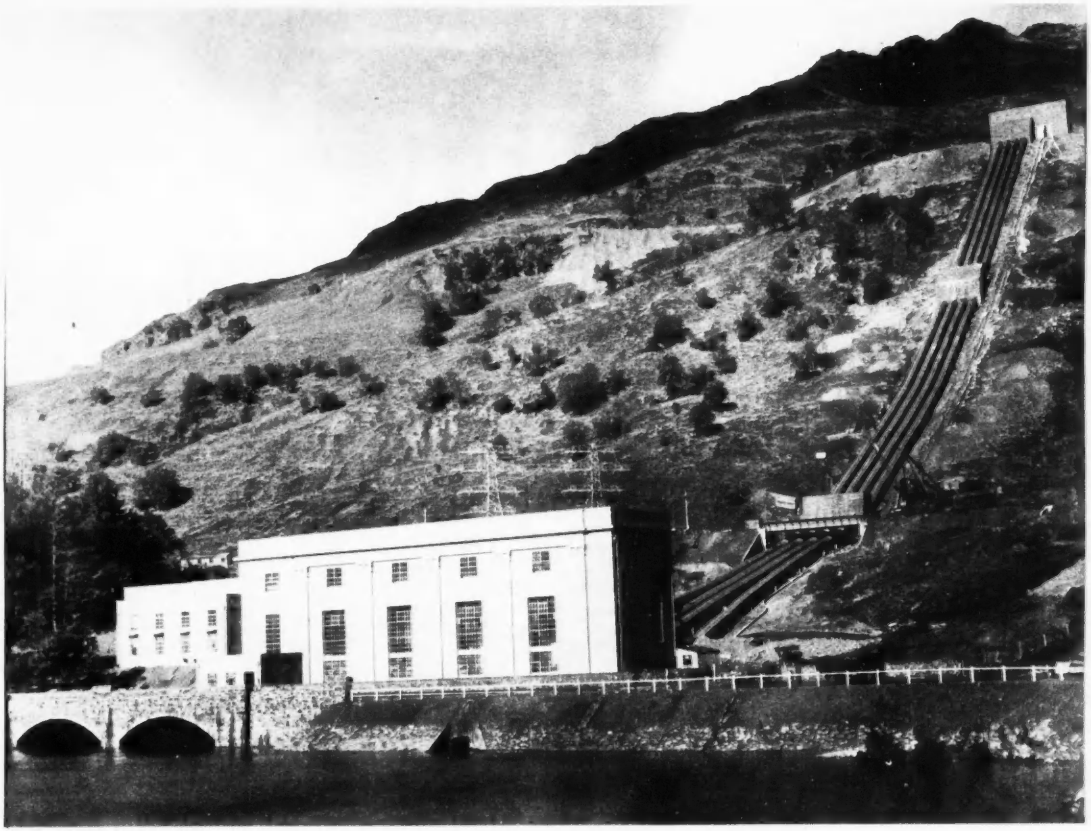
induced negative charge bound to the earth's surface which is equal and opposite. Moreover balloon observations show that the fine-weather field decreases with height quite rapidly so that the positive charge resides mainly in the lower atmosphere. At very great heights where the field has become vanishingly small the electric potential is nearly constant and of the order of 100,000 volts with respect to earth. Thus the earth's fine-weather atmosphere and the underlying surface constitute a gigantic charged condenser, the upper 'plate' being constituted by the highly conducting layers of the upper atmosphere—those layers responsible for radio propagation by reflection round the curved earth. The dielectric, which is the atmosphere, is however not a perfect insulator because of the gaseous ions produced in it by cosmic rays and the radiations from radioactive materials in the earth's crust and atmosphere. These ions provide a current which is capable of discharging the condenser in twenty minutes or so, yet it remains charged to a roughly constant potential difference. How is the charge maintained?

Wilson correctly suggested in 1923 that the source of charge was to be found in regions of disturbed weather and particularly of the thunderstorm. The thunderstorm of positive polarity separates positive charge upwards and negative charge downwards within itself and is the dynamo of the whole atmospheric system. Positive charge is pumped upwards from the upper terminal of the dynamo, and negative charge moves downwards from the lower. This charge is redistributed more or less instantaneously in the upper conducting layers and in the earth, so as to maintain the leaking condenser of the fine-weather areas in the going condition which is observed. Measurements by Wormell and others have shown that the charge transfer is of the right order of magnitude. More impressive, Whipple showed that the rather small daily variation of the earth's fine-weather field (or 'condenser' voltage), proceeding according to universal and not to local time, was in excellent agreement with the daily variation of thunderstorm activity integrated over the whole globe.

READING LIST

There is no good up-to-date text dealing with the thunderstorm from all major aspects. Quite the best on the electrical side is contained in *Terrestrial Magnetism and Electricity* (Ed. J. A. Fleming) MacGraw Hill, 1939, reprinted 1949, chapter by B. F. J. Schonland entitled "Thunderclouds, shower clouds, and their electrical effects", pp. 657–75, but it is out of date on some important aspects. Also recommended is *The Flight of Thunderbolts*, Oxford, Clarendon Press, 1950, by the same author; this deals mainly with the effects and nature of lightning. For a general understanding of atmospheric electrical work C. T. R. Wilson's article, "Atmospheric Electricity" in *Dictionary of Applied Physics*, Vol. 3, Macmillan, 1923, and B. F. J. Schonland's Methuen Monograph, *Atmospheric Electricity* (1932) are very good. *Atmospheric Electricity* by J. A. Chalmers, Oxford, Clarendon Press, 1949, is up to date but less critical.

For the thunderstorm as a whole the reader is referred to two review articles by P. A. Sheppard, "The Cumulonimbus and Thunderstorm", Parts I and II, *Science Progress*, Vol. 38, Jan. and July, 1950. This gives references to original papers.



1. The hydro-electric power station on the shore of Loch Lomond. Its turbines are operated by water brought through the mountain by four pipelines.

Power from the Highlands

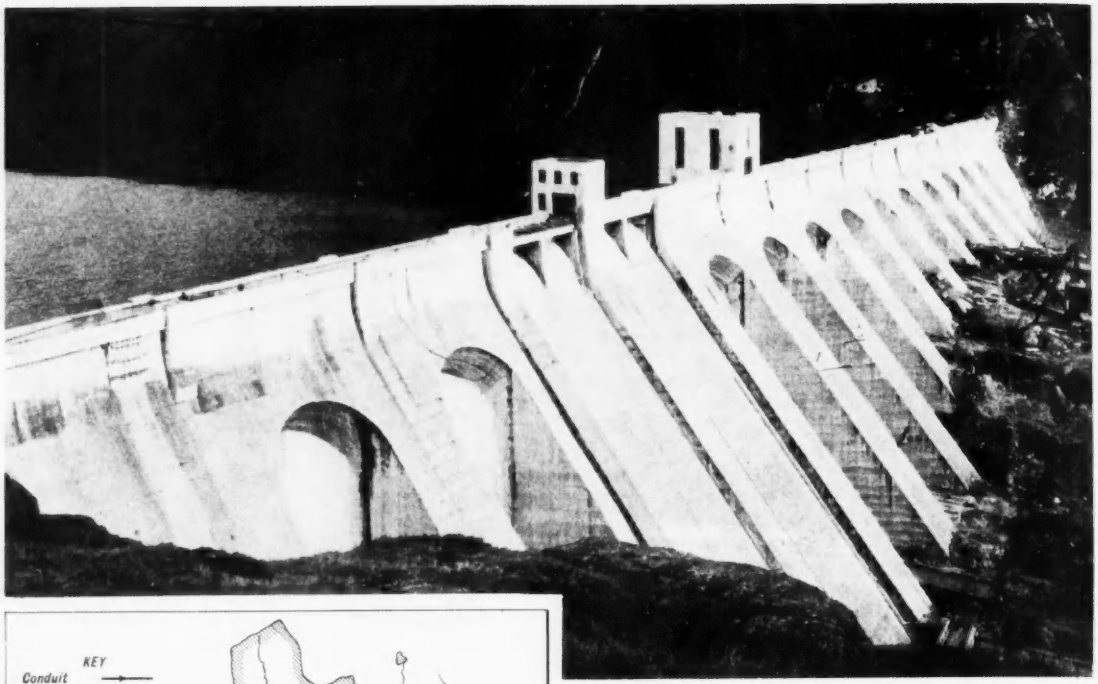
THE water power resources of Great Britain, although never likely to form a major contribution to the power economy of the country, are, nevertheless, a useful source of power which is rapidly being exploited, in particular in Scotland.

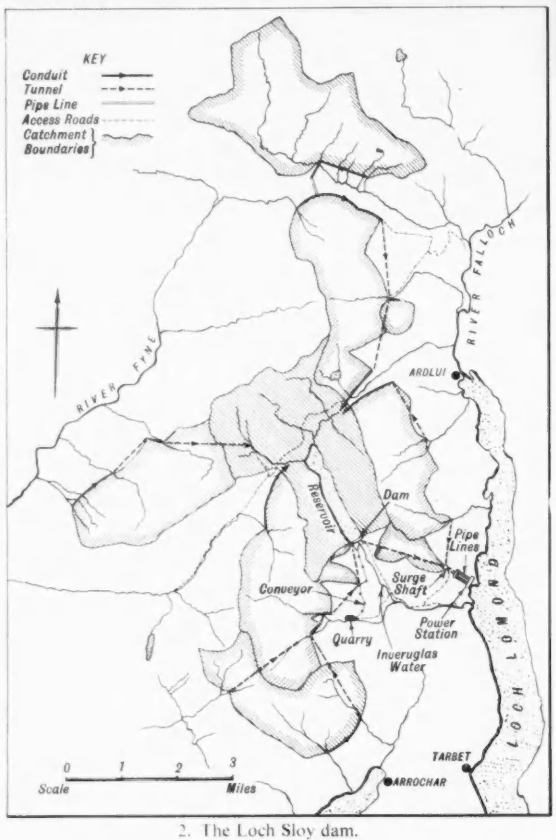
Water power exists in Great Britain in two principal areas—Scotland and North Wales. In Scotland, before the inception of the North of Scotland Hydro-Electric Board in 1943, thirteen hydro-electric plants, having a total capacity of 320,000 kilowatts, were in operation. The Board's programme envisages the construction of schemes in which there will be a total of forty-six hydro power stations, having plant capacity of approximately 1,000,000 kilowatts. Although this represents a large-scale hydro-electric system, its output is not likely to supply more than one-sixth of the total power requirements of Great Britain. This programme will be not only to add a great impetus to the industrialisation of Scotland, by the provision of cheap and abundant power, but it will also be possible for the Board to export to the South a considerable amount of power to aid the heavily loaded steam power stations in England.

Britain's largest hydro-electric scheme, which was inaugurated by Her Majesty The Queen on October 18, is that of Loch Sloy, the power station being on the banks of Loch Lomond. Not only is it the first major station to be commissioned, but is also the largest which, as yet, has been planned.

The Loch Sloy Scheme was first published in 1933 and envisaged a power station containing 130 kilowatts of plant—enough to light 2,000,000 domestic electric lamps—with an estimated annual production of 120,000,000 units of electricity during a year of average rainfall. It is designed for peak load operation which is of special advantage owing to its nearness to Glasgow and the industrial belt of Scotland.

Water is obtained from Loch Sloy, whose length has been approximately doubled and whose natural capacity increased more than 50 times, by the construction of a dam, the total length of which is 1160 ft. with a maximum height of 160 ft. at the south-eastern end. The final catchment area is 32·5 square miles. The water stored in the enlarged area of Loch Sloy will amount to 1200 million cubic feet, which is equivalent to 22,000,000 units of electrical energy.





2. The Loch Sloy dam.

3. The map shows Loch Sloy, the dam, the tunnel through Ben Vorlich and the water pipelines that feed the power station. (*Map by courtesy of "The Engineer".*)

From the dam, water is led through a tunnel 1¾ miles long through the mountain Ben Vorlich, and thence *via* two pipelines of 10-ft. diameter, branching into four of 7 ft. in diameter, which are 1500 ft. long and which lead down to the generating station at Invergulas.

The gross head under which the station operates is 910 ft. This is among the highest heads on which Francis-type turbines have been utilised. In this type of turbine, water is led in all round the wheel, the shaft of which is disposed vertically, and gates vary the flow of water to control the output. The alternator is directly coupled to the turbine and situated above it.

The general world trend to use this type of water turbine for higher and higher heads is exemplified not only at Loch Sloy but also at a neighbouring development, Glen Shira. Each of the turbines at Loch Sloy is rated at 45,000 horse power at 810 ft. head.

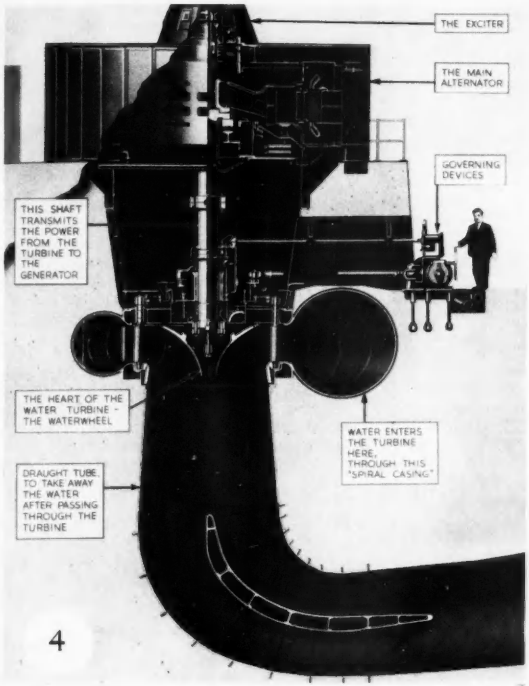
The machinery hall and the power station is 190 ft. long and 52 ft. wide, and is a steel frame structure with reinforced concrete walls.

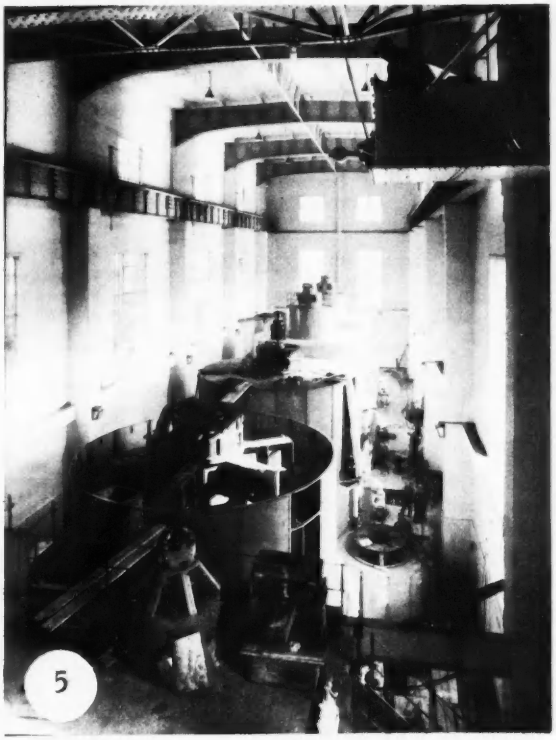
Water Turbines

Water from the pipeline is taken to a spiral casing which is of steel cast in one piece and which weighs 30 tons, having an inlet diameter of 5 ft. The cutaway drawing shows how the turbines operate.

Speed governing of the generating sets is carried out automatically by means of a servo motor. In case this fails, there is an automatic device which closes the guide vanes; operation can also be carried out by hand in an emergency.

On each of the generator bearings there is fitted a dial-type thermometer with an electric contact to operate an alarm circuit if undue temperature rise should occur.


THE EXCITER
THE MAIN ALTERNATOR
GOVERNING DEVICES
THIS SHAFT TRANSMITS THE POWER FROM THE TURBINE TO THE GENERATOR
THE HEART OF THE WATER TURBINE - THE WATERWHEEL
WATER ENTERS THE TURBINE HERE, THROUGH THIS "SPIRAL CASING"
DRAUGHT TUBE TO TAKE AWAY THE WATER AFTER PASSING THROUGH THE TURBINE
4

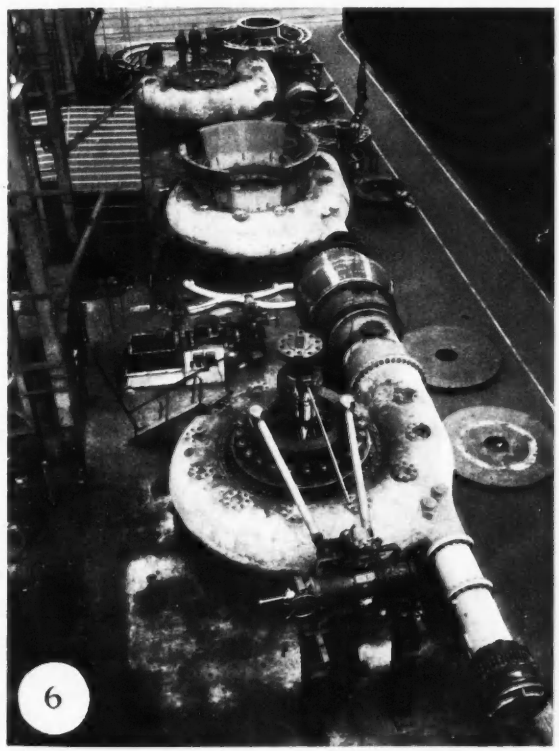


4. This cutaway diagram shows the essential elements of a typical water turbine and alternator as installed at the Loch Sloy power station.

5. Interior of the Loch Sloy power station. There are four 45,000 h.p. Francis-type water turbines.

6. The arrangement of the spiral casing and guide vanes which direct water on to the water wheel is well seen in this picture showing three of the Loch Sloy turbines being erected.

(*Photos by English Electric.*)



The 50-cycle alternator is rigidly coupled to the water turbine by means of a steel shaft 20 in. in diameter.

The alternator is self-ventilated, with fans on the upper and lower side of the rotor hub. There is a closed air circuit ventilation system with vertical coolers arranged radially outside the stator frame. The compact system of ventilation is ideal for the application of CO_2 fire extinguishers, as the volume of air in the closed circuit is a minimum. In addition, air inlets and outlets capable of supplying heated air to warm the interior of the station are provided.

The main and pilot exciters are mounted directly above the alternator and are totally enclosed. Automatic voltage control is provided by a normally inactive, quick-acting, automatic voltage regulator, which is energised from a positive phase sequence network and whose circuit includes power factor compensation for parallel running, line drop compensation, and high and low voltage protection. It operates in conjunction with a motor-operated exciter field rheostat, and there is also a hand-operated pilot exciter field rheostat.

From the generation voltage of 11 kV., the pressure is stepped up to 132 kV. by means of 35,000 kVA. water-cooled transformers. A short overhead line then carries the power to the switching station at Inveruglas, approximately 1 mile from the power station.

Two of the largest bulls to be found among the Lascaux cave paintings. They are almost 20 ft. long.

The largest mural in the Lascaux cave where paintings of about 500 animals were found.

Colour F

Lascaux
and dire
unique
time in
Festival.
cover th
cave is
lection
They ar
of prese
etched a
12,000 a
lived in
fine qual
painted
the rock
has form
paintings

The di
in Septe
Marsal a
along a
river in
chased a
into this
where th

It was
France t
were abl
visitors
man, wh
based u
paintings
of filmin
not until
He used
U.S.A. a
from Lo
provided
supporte
Flaherty,
the Vikir

The vi
to his ow
quality o

This 16
for sever
universiti
and com
cial use
Gotham

ACTH a

A GROU
nounced
p. 381)
extract ta
pharmac
similar
following
ACTH.
or not t
valuable
such a
after a tr
ably larg
cases. E
liquorice
ACTH, t
siderable
upon the
drug.

It has a

Far and Near

Colour Film of Lascaux Paintings

Lascaux: Cradle of Man's Art, written and directed by William Chapman, is a unique colour film shown for the first time in Europe at the recent Antibes Film Festival. It is a record of paintings that cover the limestone walls in a cave. This cave is declared to contain the finest collection of prehistoric paintings yet found. They are unique in their excellent state of preservation, many being as vividly etched as when they were painted between 12,000 and 30,000 years ago by men who lived in the Cro-Magnon period. This fine quality is due to the fact that they are painted on a crystalline exudation from the rock surface. This thin film of crystal has formed an ideal background for the paintings.

The discovery of the paintings was made in September 1940 by two French boys, Marsal and Ravidat. They were walking along a wooded ridge above the Vézère river in south-west France. Their dog chased a rabbit into a hole and digging into this hole, they tumbled into a cave where they discovered these paintings.

It was not until after the Liberation of France that people from other countries were able to visit the cave. Among the visitors was an American, William Chapman, who, impressed by existing art films based upon direct photography of the paintings of great masters, had the idea of filming these historic paintings. It was not until 1948 that he was able to do this. He used colour film obtained from the U.S.A. and took his shots with a camera from London, with the aid of lighting provided by a French electrician. He was supported morally in his work by Robert Flaherty, and financially, by a grant from the Viking Fund.

The vividness of his film is a tribute both to his own insight and to the remarkable quality of the paintings.

This 16 mm. sound and colour film runs for seventeen minutes and is for sale to universities, colleges, schools, museums and community groups for non-commercial use only. It may be obtained from Gotham Films, New York.

ACTH and Liquorice

A GROUP of Dutch workers has announced in *The Lancet* (Sept. 23, 1950, p. 381) their discovery that a liquorice extract taken by the mouth can produce a pharmacological effect in man which is similar in almost all respects to that following injection of cortisone and ACTH. It is too early yet to say whether or not the extract possesses any of the valuable therapeutic properties of ACTH; such a statement can be made only after a trial has been made with a reasonably large and representative series of cases. Even if clinical trials show that liquorice lacks the particular virtues of ACTH, the results might still be of considerable value in throwing more light upon the mode of beneficial action of the drug.

It has already been established, however, that liquorice extract is of value in cases of peptic ulcers. During the war, it was observed that many people suffering from peptic ulcers showed improvement after taking a proprietary medicine sold by a pharmacist in a small town in Holland. This medicine was found to contain an extract of liquorice, aniseed and iron. The active principle turned out to be the liquorice, hitherto largely used in pharmacy to mask unpleasant tastes and not suspected of having any marked pharmacological action.

A clinical trial of liquorice extract for the treatment of peptic ulcers confirmed the favourable results previously observed, but it was also found that about one patient in five developed serious side effects, including disturbance of the body water and salt balance and increase in blood pressure, symptoms familiar in ACTH therapy. The active principle in liquorice extract appears to be *glycyrrhizin*, the sweetest material occurring naturally. (It is 50 times as sweet as cane sugar.) The suggestion has been made that this chemical might produce the side effects mentioned by stimulating the adrenal gland to produce ACTH or some such natural hormone.

Royal Institution Xmas Lectures

THE children's lectures at the Royal Institution, 21, Albemarle Street, W.1. will be given this year by Professor E. N. da C. Andrade, Director of the Royal Institution, who will speak on "Waves and Vibrations." They will take place at 3 p.m. on December 28 and 30, January 2 4, 6 and 9. The subscription payable by non-members for the series of six lectures is half a guinea for children aged 10 to 17, and a guinea for adults.

Scientific Council for South Africa

THIRTEEN scientists from six countries met in Nairobi on November 21 to discuss how science could best be applied to the benefit and development of Africa South of the Sahara. They represented Belgium, France, Portugal, Southern Rhodesia, the Union of South Africa and the United Kingdom and Colonies, and met together as members of the Scientific Council for Africa South of the Sahara, a permanent body whose functions and composition were approved at an intergovernmental meeting held in London last May.

The chairman was Dr. P. J. du Toit, President of the South African Council for Scientific and Industrial Research. Britain was represented by Sir Alexander Carr-Saunders, Director of the London School of Economics and Chairman of the Colonial Social Science Research Council. Dr. E. B. Worthington, Scientific Secretary to the East African High Commission, was Secretary-General.

Films and Meteorology

A JOINT meeting of the Royal Meteorological Society and the Scientific Film Association was held on October 18th, 1950, to discuss the value of films in meteorological training and research. The speakers included Professor Sir David Brunt, and representatives of the Air Ministry and Ministry of Education and makers of scientific films. Stress was laid on time-lapse cinematography as an aid to the study of meteorological problems; and tribute was paid to the value of animated diagrams or models in teaching ideas such as the synoptic chart. Time-lapse colour films taken by Dr. Vincent Schaeffer (of the American firm of G.E.C.) were shown illustrating with great beauty the formation of cloud structures and artificial rainfall induced by 'seeding' with dry ice.

Assaying Uranium in Ores

THE Stationery Office has just published a *Handbook of Chemical Methods for the Determination of Uranium in Minerals and Ores*, price 1*s*.

The methods recommended are based on the results of four years' experience at the Chemical Research Laboratory. They include new chromatographic techniques developed for the detection and determination of uranium and other metals.

Night Sky in December

The Moon.—New moon occurs on Dec. 9d 09h 28m, U.T., and full moon on Dec. 24d 10h 23m. The following conjunctions with the moon take place:

December				
4d 08h	Saturn in conjunction with the moon	Saturn	3°	N.
10d 18h	Mercury ,,	Mercury	3°	N.
12d 01h	Mars ,,	Mars	3°	N.
14d 13h	Jupiter ,,	Jupiter	0.9°	N.
31d 18h	Saturn ,,	Saturn	4°	N.

In addition to these conjunctions with the moon, Mercury is in conjunction with Venus on Dec. 27d 21h, Mercury being 2.2° N.

The Planets.—Mercury is an evening star, setting at 16h 30m, 17h 05m, and 16h 25m, on Dec. 1, 15, and 31, respectively. Venus is an evening star but is too close to the sun for favourable observation until late in the month; the planet sets 45 minutes after the sun on Dec. 31 and can be seen for a short period in the western sky. Mars is an evening star, its times of setting being 18h 35m, on Dec. 1 and 15, and 18h 45m on Dec. 31, but it lies rather low in the sky for good observation. It is remarkable that Mars sets at nearly the same time throughout December; this is due to the fact that although it has an easterly movement amongst the constellations—its easterly motion during December is about 25°—and therefore should rise later each night, at the same time it has a northerly movement in declination which nearly compensates for its delay in rising owing to its easterly motion. The same thing occurs at times with the moon which has also an easterly motion and hence rises later each night, but at certain times it has a rapid northern movement

which largely neutralises this late rising. Jupiter is an evening star, setting at 22h 25m, 21h 40m, and 20 55m on Dec. 1, 15, and 31 respectively. The planet continues to move northward which implies that it is becoming more favourably placed for observation. Saturn is a morning star, rising at 1h 20m on Dec. 1 and 23h 30m on Dec. 31.

Winter solstice is on Dec. 22d 10h, when the sun attains its greatest southern declination 23° 26′ 45″. It may be pointed out that this does not imply that the sun is then nearest to the earth—an error which is occasionally made by amateur astronomers. The solstices have no connexion with perihelion or aphelion—the nearest and greatest distances of the earth from the sun; the former occurs on Jan. 2 and the latter on July 4, but there is a very slow change in these dates.

More Pay for Science Masters

THE new Burnham Scale, due to take effect in April, means a substantial increase in all teachers' salaries, and to many science masters the addition of around £150 to their salaries.

Fruit Tree Spraying Costs Halved

WITH the introduction of an insecticide containing 'Gammexane' winter washing of fruit trees is no longer necessary. Experience over the past two years on several thousand acres of top fruit has shown that this insecticide (sold commercially as 'Agrocide Dispersable Powder') can be applied in spring at an average cost approximately half that of the present winter and spring spraying programme involving five sprayings and the use of tar oil, DDT and nicotine. A booklet about this insecticide can be obtained from N.P. Harvey, Plant Protection Ltd., 61, Curzon Street, London, W.1. Tel. Mayfair 8802.

Nobel Prize for Cortisone Researchers

THREE SCIENTISTS who have worked on Cortisone and its medical applications have been awarded the 1950 Nobel prize for medicine. They are Dr. T. REICHSTEIN of Basle University, who discovered cortisone; and Dr. E. C. KENDALL and Dr. PHILIP S. HENCH, both of the Mayo Clinic, Rochester, Minnesota, who investigated its practical clinical use.

Dr. HENCH was recently in London, and gave a lecture to the Royal Society of Medicine on cortisone. He spoke of the search now under way to find substitutes for cortisone, and said that some 50 steroids had been studied. These were all more or less related to cortisone, but apart from 'compound F' (which had not yet been synthesised, so far as he knew, though it probably would be in the near future) none of them produced significant effects. Dr. Hench added that cortisone was now priced at 50 dollars a gram. Supplies were now sufficient to make cortisone available in limited amounts to all approved American hospitals, with growing supplies for foreign medical centres. He said he had recently seen the first specimen of ACTH from the pituitary of the Norwegian whale.

Christmas Scientific Exhibition

A SCIENTIFIC EXHIBITION illustrating a most fascinating variety of subjects will be held at the Imperial College of Science, South Kensington, from December 26 to 30. Eminent scientists including Sir Alexander Fleming and Sir Robert Watson-Watt will lecture on subjects ranging from Dinosaurs to Radar and Colour Vision to Crime Detection. Members of scientific societies and teams of students from different colleges will give demonstrations and a number of interesting films will be shown.

Admission is 2*s.* 6*d.* each session; school parties of 12 or more at 2*s.* each if booked before December 15. Further details can be obtained from the Secretary of the Crosby Hall, Endowment Fund, Crosby Hall, Cheyne Walk, S.W.3.

Television in the Home

ILIFFE'S publish a useful booklet entitled *Television in Your Home: Everything the potential viewer needs to know*, by W. E. Miller. Price 2*s.*, the book is aimed at the non-expert, and assumes little previous knowledge of television. In many ways it can be regarded as supplementing the instruction card or manual which is provided by the television receiver manufacturer.

EDUCATIONAL ANNOUNCEMENTS

Space may be reserved in this section by scientific organisations, schools and colleges for announcements of courses, appointments vacant, etc.

Details from JOHN TRUNDELL & PARTNERS LTD.
Temple Chambers, Temple Avenue, London, E.C.4
Tel. City 6537 (three lines)

FARADAY HOUSE ELECTRICAL ENGINEERING
66, Southampton Row, W.C.1.

A 4-year full-time course, which includes practical training with mechanical and electrical engineering firms, for the Faraday House Diploma which is accepted for Graduate Membership of the I.E.E.

For particulars apply Dept. E.

THE BRITISH INTERPLANETARY SOCIETY
157, Friary Road, London, S.E.15.

Membership and Fellowship is open to all interested in rocket engineering, astronomy, and space-flight.

Full particulars of membership, together with a free copy of the Society's Journal and the programme of lectures in London and Manchester will be sent on request.

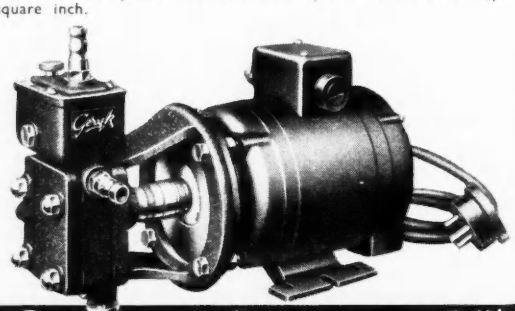
WANTED

Senior Laboratory Assistant (Male) for Boys' School. Previous knowledge of this work (Chemistry and Physics) essential. Small cottage available shortly. Apply in writing, stating age and experience, to C. Burton-Brown, Bradfield College, Berks.

Pulsometer
Geryk VACUUM or PRESSURE PUMPS

RESEARCH WORKERS Save your high vacuum pumps for high vacuum work. Use this unit for the odd jobs.

Characteristics: 1. Portable. 2. Stands on the bench. 3. ⅙ H.P. motor with trailing lead. 4. Easy to clean and service. 5. Swept volume : 1 cu.ft/min. 6. Vacuum ·01 M/M. 7. Pressure 10 lb/per square inch.



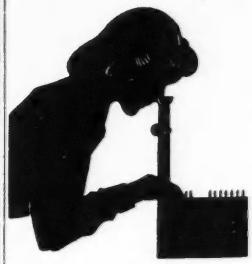
Pulsometer Engineering C° L^td^.,
Nine Elms Ironworks, Reading.

Printed and Published in Great Britain by Jarrold & Sons, Ltd., Norwich. *Editorial Offices: 244 High Holborn, W.C.1.*

SCIENCE TO-DAY

is the only British publication which gives a short weekly review of progress in science. It combines news and reviews; is at the same time readable and serious, accurate as well as prompt. Recent articles have dealt with ocean research, insect eyes, and interlocking crystals. The combination of references and a six-monthly index make it a useful starting point in any search for current information.

Editor: A. W. Haslett, M.A.
Subscription: 35s. a year (50 issues)
Specimen Copies from Circulation Dept.:
Science To-day,
104 Clifton Hill, London, N.W.8



Visual Colorimetry

The description in simple and mathematically recordable terms of *what a colour looks like.*

The
LOVIBOND TINTOMETER

now available from stock, has perfectly fulfilled this function for 70 years, and its use and popularity is still increasing.

Write for new booklet
"Colour, and the Visual Measurement of Colour" by A. J. Fawcett. Price 1s. 9d.
from *post free*
THE TINTOMETER LIMITED
SALISBURY ENGLAND

Rectophot
RAPID REPRODUCER

PERFECT PHOTO COPIES
IN YOUR OWN OFFICE
WITHIN A FEW MINUTES

•

NO DARK ROOM
NO LENS
NO MISTAKES

•

PARTICULARS FROM
A. WEST & PARTNERS LTD.
36, BROADWAY, LONDON, S.W.1
TEL.: WHITEHALL 5677

University Correspondence College

Founder: William Briggs, LL.D., D.C.L., M.A., B.Sc.
Principal: Cecil Briggs, M.A., *M.C.*
Vice-Principal: Arnold Saxelbye, M.A.Camb., B.A.Lond.
Science Director: George Walker, Ph.D.Camb., M.Sc.Syd.

★

COURSES OF STUDY

are provided for London University Entrance, Intermediate and Degree Exams., Diplomas in Public Administration and Social Studies; for General Certificate of Education (Ordinary and Advanced Levels) Oxford, Cambridge, Northern Universities, London, and others, Teachers' Diplomas, Pre-Medical, Civil Service, Local Government Promotion, Engineering, Foreign Languages, Law, etc.

Founded in 1887, U.C.C., with its staff of highly qualified Tutors, has successfully prepared many thousands of students for examinations by means of its specially planned courses of instruction. The College is an Educational Trust, not conducted primarily as a profit-making concern, its main objects being the efficiency of its courses and the success of its students. Fees are moderate and may be paid by instalments if desired. In the event of failure tuition is continued free of charge subject to clearly stated conditions. Textbook Library.

★

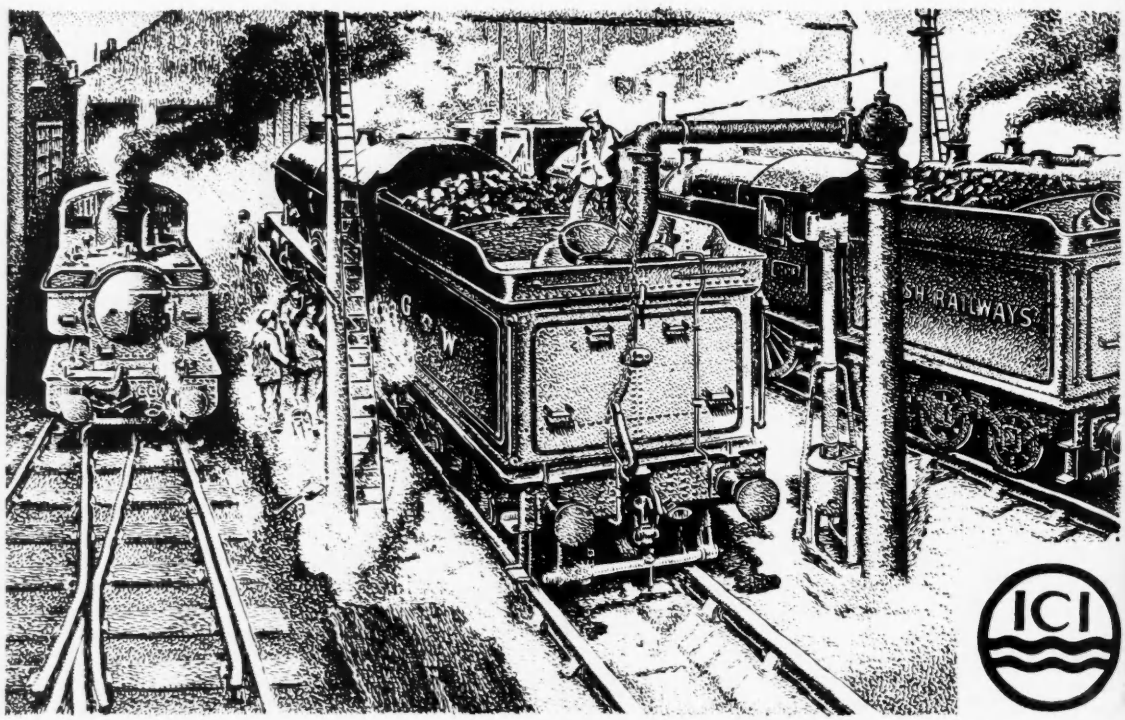
PROSPECTUS giving full particulars of U.C.C. Courses, Fees, Special Features, etc., may be had post free from the Registrar,

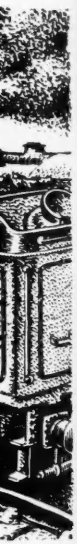
48 Burlington House, Cambridge

Water Treatment

Some industrial processes can only be carried out with soft water and industries such as dyeing and bleaching first became established in those areas in which the water is naturally soft. Nowadays, the chemist can make water suitable for almost any purpose. The origin of water treatment may be traced back to a Scots doctor, Thomas Clark, who discovered in the first half of the last century that certain types of hard water could be softened by adding lime; "Clark's method" is still the basis of the lime-soda water treatment process which is widely used in industry today. Since Clark's pioneer work, many other chemicals have been produced for the treatment of water. In 1938, for example, two British chemists, Adams and Holmes, discovered the value of synthetic resins for treating water to be used in certain industrial processes—where a water of high purity, comparable with that of distilled water, is required.

One of the greatest, but least known, achievements of the British chemical industry is to treat, every day, thousands of millions of gallons of water used in textile processes, laundries and boilers—an achievement which saves the community many millions of pounds annually. British Railways treat between fifty and one hundred million gallons of water a day in order to maintain their locomotive boilers in sound condition and free from scale. The British chemical industry also provides the housewife with soda crystals and similar alkalis which form the basis of domestic bath salts and water softening compounds.



-where
that of

chieve-
o treat,
ons of
es and
e com-
British
undred
main-
condi-
emical
h soda
m the
ftening